Investigation, Testing and Development of an RFID System for Effective Maintenance of the Existing National Transportation Infrastructure

> Dr. Erick C. Jones Abhisheksinh Rathore Sathishkumar Muthukumar

# FINAL REPORT

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# INVESTIGATION, TESTING AND DEVELOPMENT OF AN RFID SYSTEM FOR EFFECTIVE MAINTENANCE OF THE EXISTING NATIONAL TRANSPORTATION INFRASTRUCTURE

# FINAL PROJECT CLOSURE REPORT

By:

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The University of Texas at Arlington

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#### 16. Abstract

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## Abstract

This project seeks to investigate how RFID sensors can detect black ice remotely to reduce the number of accidents caused by this thin layer of ice when it is not visible. Black ice, sometimes called clear ice, is a thin coating of ice that is visually transparent and often hard for drivers to identify. The detection of this thin layer of ice is difficult from the naked human eye. Due to this fact many drivers have accidents when they lose control of their vehicles after they are on the black ice. Given this, our research hypothesizes that if black ice can be detected with remote RFID sensors, then a driver can be informed early enough to minimize accidents. The research utilizes a Design for Six Sigma (DFSS) experimental approach to test the performance of RFID based sensors on simulated black ice conditions. The results were determined based on the RFID sensors read signal strength (RSSI). The results indicate that signal strength is stronger in thinner ice slivers. This research describes our initial research hypothesis, set-up, and initial finding. We expect through further findings to use and Artificial Intelligence based algorithm that calculates the ice thickness can inform the driver through cell towers early enough to avoid the black ice condition.

# *Key Words*: Transportation, RFID System, Black Ice, Roadways & Bridges, RSSI Value, Winter Maintenance

#### **Research Focus Area**

We have identified the four research focus areas we seek to investigate during the life of the research.

- FOCUS AREA 1: Using embedded pavement sensors/ RFID to identify road conditions
- FOCUS AREA 2: Notifying the incoming traffic regarding the condition of the road
- FOCUS AREA 3: Ensuring Transportation System Vitality through Performance Management and Monitoring Systems
- FOCUS AREA 4: Innovative Funding Strategies for Future Transportation Infrastructure, and Better Maintenance of the Existing Infrastructure

This project only had limited funding, so we only investigate the first research focus area

• FOCUS AREA 1: Using embedded pavement sensors/ RFID to identify road conditions

We hope the results will allow us to move forward to the next step of our research in which we test the notification of the driver prior to them approach the danger black ice road conditions.

## **Problem statement**

This long-term research goal is to investigate how RFID sensors can detect black ice remotely to reduce the number of accidents caused by this thin layer of ice when it is not visible. Black ice, sometimes called clear ice, is a thin coating of ice that is visually transparent and often hard for drivers to identify. The detection of this thin layer of ice is difficult from the naked human eye. Due to this fact many drivers have accidents when they lose control of their vehicles after they are on the black ice. Given this, our research hypothesizes that if black ice can be detected with remote RFID sensors, then a driver can be informed early enough to minimize accidents.

# **CTEDD Objective**

This long-term research goal is to investigate how RFID sensors can detect black ice remotely to reduce the number of accidents caused by this thin layer of ice when it is not visible. The project objective was to investigate a complete system that allows for detecting black ice remotely with RFID technologies and communicate the information to drivers in time for them to address their driving pattern and or approach.

After the project team met, we sought to clarify these objectives into more detailed research objectives with measurable activities. Thus, we reorganized our project objectives to the following:

The main research objective of this initial funded research project is to determine the performance of RFID sensors in black ice simulated conditions. In order to investigate this project sought to meet 3 specific objectives.

**Specific Objective 1:** Identify and understand which technologies can be early detection systems on roads

Specific Objective 2: Identify which measures (variables) can be measured in black ice

**Specific Objective 3:** Investigate the performance of the early detection sensor in black ice conditions.

Our planned objective is to determine the performance of a myriad of RFID tags, (inexpensive sensors) that can be used in simulated black ice conditions. We hope to have a matrix chart that can be used for the next phase of our research. Our expected outcome would be a Matrix chart showing the performance of the tags based on simulated ice thickness.

# 1. Introduction

Black ice is a thin transparent film of ice on the top surface of roads and bridges which easily blend into the surface of the road. Nearly, 900 people are killed, and 76,000 people are injured in snowfall or sleet every year, according to the Federal highway Administration. The formation of black ice causes huge losses and damages to the government properties, human life. Federal government has taken various precautionary measures for treatment and prevention of black ice. About 2.3 billion dollars are invested annually on snow and ice control methods yearly.[1] Through this project wear trying to investigate the early detection tool to alert the drivers moving through such road conditions.

Black ice usually forms over late night or early morning as the temperature continues to drop. Common places for black ice formation are on bridges, overpasses and shaded areas of road. Areas where surfaces get rapid moving winds from top and the bottom are prone to such conditions. Apart from regular precautionary measures by the drivers such as using winter tires, slowing down when you see possibility of black ice. This are few anecdotes to the existing problem but not a full proof solution.

Hence, we saw a need to develop a road embedded RFID system to be installed, preliminary over bridges for early detection of black ice. The main goal is to alert all the passing-by drivers about the road condition and in-turn they can follow the precautionary actions accurately. Side-by-side we also want to build a platform to alert the transportation authorities regarding the condition, which would help them take necessary maintenance steps to further improve the conditions as early as possible. Driver safety is our outmost priority throughout the project, hence we want to extend this project further into application stage during our next grant so that we can build a transmission channel of this data in the form of alerting mechanism to the drivers and highway authorities.

The first specific objective of this project is to identify, investigate, and evaluate the RFID Technology reliability applied in Infrastructure maintenance and driver security. The second objective is to identify, test, and evaluate RFID Technologies in transportation safety and maintenance response. The third specific objective is to evaluate the feasibility, safety impacts and economic benefits of the RFID use on Infrastructure. [1]

The long-term goal of this research is to provide a design for the future state-of-art transportation infrastructure by capitalizing on modern technologies to automate, to monitor and to improve the maintenance of the infrastructure and status of the infrastructure in real-time. These goals are relevant to the focus area 2 of innovative funding strategies for future transportation infrastructure and better maintenance of existing infrastructure. The project also relates to the focus area 3 of ensuring transportation system vitality through performance management and monitoring systems.[5]

#### 2. Background and Literature Review

Radio Frequency Identification is the use of radio waves to communicate between a transponder and an interrogator. An RFID system is made of readers and tags which interact through antennas by converting electrical signals into radio waves. Communication using reflected radio energy dates to the early 20<sup>th</sup> century in the form of the Identify friend or foe (IFF) transponder that was used by the allies during the second world war for identification of friendly aircraft. Whether or not we realize it, radio frequency identification (RFID) is an integral part of our life. RFID increases productivity and convenience. But today RFID has many applications in areas such as supply chain, access control, toll tags/ transport payment, e-passports, automotive security, livestock, healthcare.

[1]

A high-level RFID system requires the type of tag for application between active and passive, Power sources, tag frequencies, writing capabilities, antennas and a reader/scanner. Tags comes in various shape and size based on its application. The organization must choose that fits it is needs. The tag's primary function is to transmit the information stored in the tag to the rest of RFID system. The two basic types of tags are active and passive. Active ones have a on-board power source through a small battery with additional circuitry to provide a long read range. Integrating the battery requires a plastic enclosure for both safety and design purposes. This additional requirement increases the cost considerably compared to passive tags. While passive tags do not have a power source. The tag is powered by electromagnetic power obtained from the antennas. The elimination of a power source makes this tag less expensive with simple and compact design with a drawback in the form of limited read range. The tag must be in the close proximity of the antenna in order to obtain the required power for transmitting the signal. The antenna in the RFID system is used to receiving and transmitting the RF signals from and to the tag by the reader. A signal antenna can be used when the angle of the tag and the reader are constant.

According to the U.S. Department of Transportation, over 70 percent of the US is considered a snowy region. During the icing of pavements in cold weather, the speed must be reduced drastically to avoid skidding and losing control over the wheels avoiding accidents [1]. Let us understand what black is, it is a glaze formation on the surface of the road, which is produced by light freezing rain, snow or melting ice. It is called 'black ice' because it tends to look like the rest of the pavement on the road which makes it difficult for the driver to identify. It forms most commonly at night or early morning. It usually starts forming over bridges because the cold air can cool both the top and under the bridge or overpass, thus we will be implementing it on the bridges first and later other accident-prone zones.

Our study is based on early detection of black ice formation with immediate precautionary actions to be taken in the form of driver notification and alerting the highway authorities for road maintenance. Our preliminary study is to understand the viability of the sensor technology to be used for operation. How does various tags perform in extreme weather conditions and are they able to respond with positive results? We then consider selection of independent and dependent variables, for our analysis. As thickness of ice sheet is unpredictable, thus it forms a independent parameter. And based on that knowledge we embedded RFID sensors on the asphalt to measure the RSSI signal strength. We hypothesize that with changing value of ice thickness their has to have a relation with the RSSI. How would RSSI value change based on the ice thickness forms one of the major objectives of our project. Thus, we take RSSI as our dependent variable for this project research.

The next concept is understanding the RSSI value. When you receive a signal from RFID to the antenna, you receive its signal strength or power level. It is typically measured in decibels per milliwatt, or dBm. It is related to two physical properties on a logarithmic scale. For RFID we measure the change in power level to do this experiment, concerning to a single milliwatt.[4] In any sort of RFID reader, every reader is related to Received sign quality Indicator additionally called RSSI esteem. They give us a thought of how well a tag is reacting in a read zone. This is a decent pointer how well a tag is working regarding to a different condition. This tags likewise accompany a disadvantage, the RSSI worth doesn't give us the separation of the tag from the radio wire in a detached RFID framework.[6] This is mostly because of different natural variables that influence the read capacities of the reader. This is because of the numerous RFID variables can influence a label's range in a latent framework; along with these lines' reader, RSSI alone is anything but a dependable estimation to utilize when figuring label separation. Rather, other label information esteems, for example, the label's understood rate (for example the occasions a tag is read every second) and reaction time (for example the measure of time it takes the tag to react just because) ought to be utilized notwithstanding RSSI when performing such computations.[6]

Several research studies have been carried out to understand the relation between RFID tags and their working under below zero temperature. Low temperature affects various parts of the RFID label usefulness. Likewise, the impact of conceivable amassing of the ice on the label surface is discussed aspects of RFID tag functionality. Also, the effect of possible accumulation of snow and ice on the tag surface is discussed. Thus, we base our development of the project on understanding on the fact that with layers of formation of snow over the embedded RFID, and we compare the RSSI value deviations in the current environment to detect black ice formation.[7]

The newest of the frequencies is the Gen 2 standard, made popular by the RAIN initiative. Gen 2 passive tags are both widely accept and used, in most RFID applications. We can see this in Bolton's scale of RFID Standards, Figure x. In this figure, the tag types are listed by what quantity of tags are in the market, the greatest being RAIN (Jones, Gray, Wijemanne, and Bolton).

The Radio Frequency and Auto-Identification (RAID) labs at the University of Texas at Arlington were created to provide an unbiased and reliable source of RFID information. The RAID lab's main research goals are concerned with the implementation and standardization of RFID in Healthcare, manufacturing, Information systems, quality control, Aerospace, warehousing, process analysis, automated sensing, Etc. We have had a history of bringing research dollars, funding students, and publishing papers. [multi-surface paper]

Dr. Erick C. Jones, RAID lab director and Professor at UT Arlington, has published over 150 manuscripts on the topic of RFID. Previous contracts and grants include NASA, NSF, NIH. There are close to a dozen Ph.D. students, 40 Masters Students, and 20 undergraduates. Our current team is 5 Ph.D. candidates, 7 Masters Students, and 4 undergraduates. Recently, RAID LABS was awarded with a grant of \$200,000 from the National Science Foundation (NSF) to research on COVID-19. The RAID labs have provided such information on tag performance to companies and organizations in the past and presently with the unprecedented situation of the large-scale pandemic with NSF. For this research on tag performance, different parameters were taken into account; distance of tag from reader, different orientations of tag, to test the readability of tags attached to different materials, varying signal strength with respect to tag orientation and distance from reader.

#### DFSS-R introduction

DFSS-R is derived from Six Sigma methodology. It was developed by Dr. Erick C. Jones in 2006 (Jones et al. 2011). DFSSR is a research methodology focused on reducing variability, removing defects, and getting rid of wastes from processes, products, and transactions. It contains three main

predominant phases: plan, predict, and perform. The methodology is then broken down into seven main phases: define, measure, analyze, design, identify, optimize, and verify.[16]

#### Define

Within the *define* phase, a problem statement is to be created and the basis of material from which the process will draw information from is to be defined. It is critical to correctly denote all the information and resources that will be used for future phases of the process. This allows for the writer to begin framing his/her thoughts through discerning relevant subjects and further investigating the subjects necessary to enrich the subsequent phases. The *define* stage also serves as a springboard to educate the reader and prospective client for this method. Prospective tools that can be utilized are thought process mapping, system mapping, and interview processes among other observational techniques. Furthermore, standards of performance are created for the project to follow. Doing so aids in ensuring the process remains on course throughout the experiment as well as for evaluation purposes of what the overarching process is trying to achieve. The result of a successful *define* phase is a clearly defined problem statement and foundation for the methodology to propel itself upon.[16]

#### Measure

The *measure* phase is that in which the metrics are established for the methodology. It is in this phase that the validation of measurement systems occurs. Additionally, the capability to accurately quantify this data and criteria for success must also be determined. This can be attained through the use of hypothesis testing, flowcharting, analysis of variance, and other graphical methods. It is crucial to establish a correct metric from the tools for it will determine if the solution will successfully address the problem. Without the correct metric, the rest of the methodology will be undesirable. Upon completion of this phase, the finalization of performance standards should be fortified.[16]

#### Analyze

The *analyze* phase is that in which the identification of the sources of conflict occurs in addition to screening potential causes. It is here where tools such as fishbone diagram, Pareto analysis, multivariate charting, and other statistical observations transpire. Fishbone diagrams are useful for determining the causes of a problem and feeding them into one central issue. Pareto analysis can be applied in a multitude of ways to observe data and patterns from the figures. It focuses on the principle of the 80/20 rule in which 80% of the issue can be solved by addressing 20% of the problem. The results of this tool are then displayed in a Pareto chart with a graphical representation where the sources of the problem are displayed as well as a linear summation that details the contribution of each source. Other forms of regression and multivariate analysis are useful for interpretation and elimination methods. The result to take away from this phase is statistical information upon which empirical decisions can be made.[16]

#### Design

Within the *design* phase, decision analysis and solution storming takes place. This is where possible solutions are created to address the problems obtained from the *analysis* phase. Some tools employed by the *design* phase are scenarios, multiple response optimization, and formulating theories of constraints. It is important to thoroughly deliberate a possible solution that does not create more problems. The goal of this phase is to come away with possible solutions which will be further investigated in the subsequent phases.[16]

#### Identify

For the *identify* phase, the focus is on impact analysis. This section lays out what the return from the solutions will attain. Some mainstay tools for this section are cost-benefit analysis, return on investment (ROI) analysis, 5-S, and mistake proofing. These tools are used to justify the courses of actions being investigated by the DFSS-R. The ROI is a particularly beneficial tool to convey the financial aspects to potential investors. Cost-benefit analysis can have a general approach that lays out more than just financial returns which may produce a tipping factor when multiple financial avenues seem desirable. In addition, mistake proofing is pivotal to this phase where a solution is meant to fully address all potential issues. The take away is a direction for the methodology to pursue.[16]

#### Optimize

The *optimize* phase is where it all comes together. It is here where the process establishes operational analysis and integration analysis of all the preceding phases. Fine tuning occurs of each phase to find the prime course of action. The scenarios are broken down and evaluated based upon how well they address the metric. New scenarios are compared to previously analyzed data and conducted as trials. These are then repeated, analyzed, and modified until a final methodology is definite. [16]

#### Verify

Finally, it is the *verify* phase that proves the outcomes by results verification, redefining the new capabilities, and closing documentation. This includes implementation of what has been proposed by the methodology. To accomplish successful execution continuous improvement, control plans, and mistake proofing are focused upon. Mistake proofing is revisited as part of continuous improvement. Both tools are contained within a control plan that is to be conducted and evolved. From this phase, a final product and maintenance regiment is to be obtained. [16]

## 3. Research Hypothesis and Objectives

Our overall research hypothesizes that if black ice can be detected with remote RFID sensors, then a driver can be informed early enough to minimize accidents. In this project we are hypothesizing that RFID sensors can perform in black ice conditions. This will be tested with our main objective of determining the performance of RFID sensors in black ice simulated conditions. Other hypothesis are correlated to our specific research objective.

**Specific Objective 1:** Identify and understand which technologies can be used for early detection systems on roads

Hypothesis: We hypothesize that some RFID tags perform better in ice than others.

Specific Objective 2: Evaluate the performance of the measures (variables) in black ice

**Hypothesis:** We hypothesize that some measure provides more accuracy when calculating performance.

**Specific Objective 3:** Investigate the performance of the early detection sensor in black ice conditions.

Hypothesis: We hypothesis that some RFID tags will perform better when signaling drivers.

Our planned objective is to determine the performance of a myriad of RFID tags, (inexpensive sensors) that can be used in simulated black ice conditions. We hope to have a matrix chart that can be used for the next phase of our research.

# 4. Methodology

We will use our RAID LABS Methodology DFSSR, which includes a Plan, Predict and Perform Phases and include seven specific steps. The diagram shows and generalized approach. The detail below are the specific steps we used on the project.



The overall methodology used for this project was derived from the RFID and Auto-ID Deployment (RAID) Labs and is known as Design for Six Sigma Research (DFSS-R). The PI- Dr. Erick Jones developed this methodology to act as a framework for an effective and efficient management of research projects. In this project we introduce a Design for Six Sigma Research (DFSS-R) methodology that allows for reliability testing of RFID systems. The research methodology uses a modified sequential design of experiments process to test and evaluate the quality of commercially available RFID technology. Traditional research methodology is based on the recognition of many companies as a means for reducing defects, increasing company productivity, and improving company profitability. The DFSS-R methodology was utilized to test each of the specific objectives. The experiments were conducted in a lab environment where conditions are ideal, and interference is minimal. A description of each testing procedure is followed by the results of the test. The results of each experiment were recorded and analyzed. The analysis of the research studies is discussed below. [9]

# 4.1 DFSS-R approach for this project

**Plan (Phase):** The plan phase includes two basics steps, Defining the research goal and problem definition. Second step is Measure, where we setup accurate metrics and data collection procedure needed for the research completion.

**Define (Step):** We defined the sensor technology and equipment that could be used. We validated the existing technologies that are relevant for the project. Below are the RAID LABS equipment profile.

#### Equipment

RFID technology have numerous application such as asset tracking, inventory cycle counting, highway tolls. To understand the application of RFID, an in-depth knowledge of RFID and its components becomes highly important. Radio-frequency identification (RFID) is the wireless non-contact use of radio-frequency electromagnetic fields to transfer data for the purpose of

automatically identifying and tracking tags attached to assets. The tags are largely classified into low frequency (LF), High Frequency (HF), and Ultra-High Frequency (UHF).[11]

RFID system requires reader, antenna's, and tags in order to function. The tag cost is highly depended on the tag type, tag volume and type on in-lays. The ultra-high frequency (UHF) band within the R0046 spectrum ranges from 300 MHz to 3 GHz; however, most UHF RFID systems operate between the 860 – 960 MHz bands. The primary exceptions are RFID systems that operate at 433 MHz and 2.45 GHz. [11,12] In Table 1, we defined four tags that were viable and available at the RAID LAB.

Manufacturer	Model	Cost
Atlas RFID	Ironside Micro RFID Tag	\$8.20
Atlas RFID	HID Inline Tag	\$6.90
MetalCraft	Universal RFID Asset Tag	\$3.15
Intermec	Asset RFID Tag	\$2.9
Zebra	MC3330R Long Range UHF Reader	\$2,592

Table 1: Experimental Equipment and costing

The MC3390R long-range RFID handheld reader brings a new level of efficiency and accuracy to inventory management, order fulfillment, cross-docking, and more. The integrated long-range antenna supports a best-in-class RFID read range, and coupled with Zebra's high-performance ASIC radio technology, delivers higher throughput, so inventory counts can be accomplished more quickly and accurately. With Zebra's signature rugged design, the MC3390R is built for your semi-industrial environments, yet is lightweight with the right ergonomics for all-day comfort. And the large touchscreen, physical keypad and Android OS deliver an intuitive and flexible platform for your RFID application needs today and tomorrow.[10] This handheld reader was available at the RAID LAB for immediate use for ice layer detection using RFID sensors.



Various software's and data analysis tools were used for data collections and interpretations. We used Excel for data collection and management and MATLAB for regression analysis and finding out the R squared value for the scatter plot. RAID LAB is also equipped with Impinj speedway fixed reader, which was used for data verification of collected data from the handheld reader.

We expect to meet Specific Objective 1: (Identify and understand which technologies can be used for early detection systems on roads) in this step. We expect to measure 10 Gen 2 tags from the RAID Labs. During this process we took more than 15 observations per tag to verify the accurate RSSI signal strength with varying the distance from the reader.

**Measure (Step):** We set up accurate metrics to figure out areas of roadways which needs a regular detection of black ice condition.

We expect to meet the Specific Objective 2: Identify which measures (variables) can be measured in black ice. We know that the output variable is RSSI as mentioned in the literature search. Using a Design of Experiments approach with a two by two design as described in the literature search. RAID uses Dr. Jones, the lab directors' approach as defined in his paper (Using design of Experiment to test RFID portals).

We can see an example calculation is below for Design of Experiment:

For our experimentation, we have used one independent variable and one dependent variable. The independent variable is Ice layer thickness and dependent is Received signal strength indicator (RSSI). When executing a full factorial experiment, a response is obtained for all possible combinations of the experiment. Because of the large number of possible combinations in full factorial experiments, two level factorial experiments are frequently utilized. In this research as we just Have one predictor variable and one independent variable, thus it does not apply to this objective. We do want to research in-depth, approach by taking many other factors such as antenna distance, horizontal and diagonal length from the tag. Two factor, two level experiment would require four trials (i.e., 2x2 = 4) to address all assigned combinations of the factor levels. The specific situations to which a DOE is being applied will affect how factors and levels are chosen. Factor levels also can take different forms.

**Predict (Phase):** These steps are what we use for redesigns. Our current funding only allows for preliminary studies. So, this was more static for this project.

#### **Design (cyclical steps):**

Analyze (cyclical steps): In the predict phase analysis is carried out to figure out how accurate is our policy in implementing to the roadways We will provide the details of analysis in the results sections. Our main performance variable is R squared.  $R^2$  value denotes the variance between the predictor and the dependent variable. In statistics, its main function is to predict the future outcomes of the test observations and provides the measure of how well fitted are the models with respect to the trendline. The values of  $R^2$  is explained in detail in the result section.

**Identify** (cyclical steps): This section lays out what the return from the solutions will attain. Some mainstay tools for this section are cost–benefit analysis, return on investment (ROI) analysis, 5-S. This step helps us understand what the mistakes are made in this research can be corrected in the

next one but also making sure there is no repetition of it. We call this 'Poka- yoke' also called as mistake proofing.

#### **Perform (Phase):**

**Optimize (summary steps):** This is where it all comes together. It is here where the process establishes operational analysis and integration analysis of all the preceding phases. Fine tuning occurs of each phase to find the prime course of action. The scenarios are broken down and evaluated based upon how well they address the metric. New scenarios are compared to previously analyzed data and conducted as trials. These are then repeated, analyzed, and modified until a final methodology is definite.

**Verify (summary steps):** Finally, it is the verify phase that proves the outcomes by results verification, redefining the new capabilities, and closing documentation. This includes implementation of what has been proposed by the methodology. To accomplish successful execution continuous improvement, control plans, and mistake proofing are focused upon. Mistake proofing is revisited as part of continuous improvement. Both tools are contained within a control plan that is to be conducted and evolved. From this phase, a final product and maintenance regiment is to be obtained.[9]

#### 5. Results & Observations

**Results of Specific Objective 1:** Identify and understand which technologies can be early detection systems on roads. In this study, we had used the Ultra High Frequency Class Gen 2 (higher read range and active location tracking) tag with frequency ranging from 860 - 960 MHz for evaluating the relation between RSSI signal strength with various ice layer conditions. The conditions were created using a refrigerator to reach a temperature of  $35^{\circ}$  F –  $5^{\circ}$  F and replicate be an ice layer over the RFID tag. We also took the RSSI value readings for the same tag at normal conditions to identify the change in RSSI value. We calculated 15 readings for each case and found out the average RSSI value in terms of decibels. Comparing this average with various conditions

helps us understand how the RSSI value would change with ice layer formation on road embedded RFID tags.

**Result of Specific Objective 2:** Identify which measures (variables) can be measured in black ice. The two specific measures considered are received signal strength indicator (RSSI) and ice thickness. Here, Ice thickness is taken as independent variable and RSSI is a dependent variable.

Looking at the table below we were able to identify the relation between RSSI and ice thickness. With increase in ice thickness we saw a gradual decrease in RSSI value. Thus, they share an inverse relation, which further helps us to predict the future values based on higher thickness of sheet using the scatter plots and data analysis using AI algorithm.

**Result of Specific Objective 3:** Investigate the performance of the early detection sensor in black ice conditions. Using sensors with various frequency we were able to identify that sensors with higher frequency range were able to perform better than the ones with lower bandwidth. With better and higher bandwidth sensors we could further improvise our research with accurate prediction of ice formation and notify to the drivers and roadway department so that necessary actions are taken to avoid accidents.



**Picture 2**: Passive UHF RFID tags used for the experimentation Picture shows four RFID tags used for research and data Analysis



To conduct a suitable investigation of the possibility of using RFID tags with a stationary reader in that environment i.e., snowy weather conditions to monitor/detect the snowfall and alert the drivers/cleanup team, all phases of this model will be used in this project

0	Task Name	Duration	Start	Qtr 1, 2019         Qtr 2, 2019         Qtr 3, 2019         Qtr 4, 2019           Jan         Feb         Mar         Apr         May         Jun         Jul         Aug         Sep         Oct         Nov         De
1	Introduction & Research Goals	12 days	Tue 1/15/19	
2	Define Phase	25 days	Thu 1/31/19	
3	Measure Phase	47 days	Thu 3/7/19	- · ·
4	Analyse Phase	48 days	Mon 5/13/19	*
5	Design Phase	41 days	Thu 7/18/19	
6	Optimize Phase	27 days	Fri 9/13/19	
7	Results & Conclusion	35 days	Tue 10/22/19	*
		Dia	turo A. G	antt Chart of the Project Timeline

As shown in figure 1, we first bring clarity to the problem by defining the importance of road safety and how black Ice is turning out to be a lead cause of several accidents on road. For the experimentation we have used 4 Gen 2 sensors with ultra-high frequency for this experiment.

## Sensor classification:



Tag selection was done based on the operating frequency, material durability, IP rating and importantly the cost. The specifications were selected to make sure they exibit all the necessary condition for application and are also available at a affordable price range. Utilizing the latest generation of Gen 2 silicon supporting 512 bits of user memory within small, durable form factor. [11,12,13,14]

Table 2: Sensor	Specifications
-----------------	----------------

Sr. No.	Item Model	Item Description	Frequency
1.	Confidex Ironside Micro RFID Tag	UHF Class 1 Gen 2 Tag	868 – 928 MHz
2.	HID Inline Tag	UHF Class 1 Gen 2 Tag	860 – 960 MHz
3.	Universal RFID Asset Tag	UHF Inlay Gen 1 Tag	915 MHz
4.	Intermec RFID Tag	UHF Gen 2 Asset Tag	902 – 928 MHz

Looking at the table below, we had one independent variable i.e. Ice Thickness and one dependent variable which was RSSI Value. We used four passive UHF RFID sensors based on their operating frequency and signal strength. From Figure 2, at a constant distance, the RSSI value varies based on the tag signal strength. The ones with the higher frequency bands performed better, indicating better signal strength.

Independent Parameter	Ice Thickness
Dependent Parameter	RSSI Value

# 5.1 RSSI Strength without Ice Layer

Sr. No.	Тад Туре		RSSI Value (dB)
1	Confidex Ironside Micro RFID Tag	Sensor 1	-39
2	HID Inline Tag	Sensor 2	-37
3	Universal RFID Asset Tag	Sensor 3	-43
4	Intermec RFID Tag	Sensor 4	-38

# Table 3: RSSI Strength without Ice Layer



In table 3, we used two ice slabs with variable thickness for replicating the ice condition over the road. The value observed has considerably increased over the signal strength without the ice layer formed. Secondly, as the thickness increases the RSSI value decreases indicating an indirect relation between ice thickness and RSSI Value.

# 5.2 RSSI Strength with variable thickness of ice layer

Sr. No.	Ice thickness (cm)		RSSI	Value	
		Sensor 1	Sensor 2	Sensor 3	Sensor 4
1	0	-43	-38	-37	-39
2	0.5	-44	-40	-41	-42
3	1.5	-48	-45	-44	-47
4	2.5	-52	-53	-52	-56
5	3.5	-55	-56	-58	-59

Table 3: RSSI Strength with variable thickness of ice layer



Figure 3 depicts the change RSSI reading based on four value of ice thickness and without Ice layer, we can clearly see reducing levels of signal strength as the thickness of ice sheet increases. Hence it helps us identify that our hypothesis of increase in ice thickness leading to reduction of RSSI value stands correct.

# 5.3 Scatter Plot of RSSI value with Ice thickness

Using regression analysis, a powerful statistical method that allows you to examine two or more variables of interest, we were able to find a relation between the dependent and independent variable. This allows us to predict the future changes in RSSI value and how that would affect the changing thickness of ice sheet. From figure 4, we see a relation between RSSI value and changing thickness of ice slab. Using regression analysis, we were able to predict how the RSSI value will change if we further increase the ice layer thickness. This concept can also be applied visa-versa, by understanding the RSSI value we can identify the thickness of the ice sheet and generate a threshold thickness after which a cation sign should be altered to the drivers.

Looking at the chart, we can clearly observe that with ice layer formation over the tag, the readability range drastically drops. Thus, our hypothesis stands correct, with an increase in distance or any kind of obstruction to the tag in the form of the ice layer led to an increase in the RSSI value. In figure 4, ' $R^{2}$ ' squared value provides a measure of how well observed outcomes are replicated by the model, based on the proportion of total variation of outcomes explained by the model. It is simply the square of the sample of correlation coefficient between observed outcomes and the predictor value. We have derived the r squared value to be 92.02% (0.9202) which is a well fitted scatter plot and predicts accurate forecast using the trendline.

#### Variables:

#### **Dependent Variable**

RSSI; Received Signal Strength Indicator – This value indicates the power of Signal Strength from the RFID sensor. Shown, on the Y-axis in decibels.

#### **Independent Variable**

Ice Thickness – We simulate the ice condition and perform the mixture of ice thickness at various levels shown on X-axis in centimeters.

#### **ANOVA Testing**

Analysis of Variance on data for two variables. The analysis provides a test of the hypothesis that each sample is drawn from the same underlying probability distribution against the alternative hypothesis. It is used to determine weather there are any statistically significant differences between the means of two or more independent variables.

#### Following are the data analysis measures used:

 $\mathbf{R}^2$  Value - The r squared value gives goodness-of-fit measure for the given liner regression model. The r squared value of 92.02% (0.9202) indicates a well fitted scatter plot with smaller differences between observed data and the fitted data. It also helps us predicts accurate forecast of variation in RSSI and ice thickness using the trendline.

**Adjusted R-Squared** – It is a modified version of R squared that is adjusted for improving the model. As in our case, there has been slight reduction to 91.45% (0.9145) indicating no new variable would improve our model.

**Standard Error -** Standard Error measures the accuracy with which the sample distribution is represents a data using standard deviation. It also tells how much the data deviating from the mean is. In our research, the value is 1.9 which tells that 1.9 % is the deviation from the fitted line.

Table 4: ANOVA	Table	depicting	the R <sup>2</sup>	Indicator
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Regressio	n Statist	tics			
Multiple R	0	.959284			
R Square	0	.920226			
Adjusted R Squ	are 0	.914528			
Standard Error	1	.944314			
Observations		16			
					Significance
	df	SS	MS	F	F
Regression	1	610.5125	610.5125	161.496	4.4656E-09
Residual	14	52.925	3.780357		
Total	15	663.4375			



# 6. Conclusion

This study investigates the feasibility of Radio Frequency Identification (RFID) technology in tracking real-time conditions of national transportation infrastructure such as highways and bridges. Experiments were conducted to study the application of the RFID sensor's signal strength as an indicator of ice formation on roads. The initial hypothesis was that the formation of ice affects the electromagnetic waves. The strength of these waves is quantified as Received Signal Strength Indicator (RSSI) which was the primary focus of our study. In previous sections of this report we investigate the correlation between RSSI and the thickness of ice on road. The explanation behind this was that if there is more ice, then the electromagnetic waves must penetrate through greater resistance in order to reach the antenna, which in turn would result in a lower RSSI value. Experiments conducted using different RFID sensors proved our hypothesis of negative correlation between these two variables.

As mentioned in the future scope section, this technology will provide real-time status of roads and bridges to the government and possibly also to the people who are using those roads. The main purpose of this study was to develop a system that would help prevent accidents during snowfall and sleet by updating the authorities. Ensuring the safety of roadways has always evolved over time and with new advancements in technology, we can reduce the number of accidents even further.

Our overall research hypothesizes that if black ice can be detected with remote RFID sensors, then a driver can be informed early enough to minimize accidents. In this project we are hypothesizing that RFID sensors can perform in black ice conditions. This was tested with our main objective of determining the performance of RFID sensors in black ice simulated conditions. Other hypothesis are correlated to our specific research objective.

**Specific Objective 1:** Identify and understand which technologies can be early detection systems on roads

Hypothesis: We hypothesize that some RFID tags perform better in ice than others.

**Result:** Looking at the results we saw that, sensors with no ice formation performed better than ones with ice layer above it.

Specific Objective 2: Identify which measures (variables) can be measured in black ice

**Hypothesis:** We hypothesize that some measure provides more accuracy when calculating performance.

**Result:** We were able to investigate the performance of tag based on RSSI vs Ice Thickness. This led to an understanding of the inverse relation between the two variables.

**Specific Objective 3:** Investigate the performance of the early detection sensor in black ice conditions.

**Hypothesis:** We hypothesis that some RFID tags will perform better when signaling drivers.

**Result:** Using sensors with various frequency we were able to identify that sensors with higher frequency range were able to perform better than the ones with lower bandwidth.

## 7. Limitations

According to our calculations and observations, we see that there exists a strong negative correlation between the Received Signal Strength Indicator (RSSI) value and the ice thickness. It is known that water has very low electrical conductivity, but the presence of salts enables the electromagnetic waves to penetrate through them at the cost of signal strength. This change in RSSI can be considered as an indicator of ice formation and the magnitude of these signals can help highway authorities determine the severity of the situation to deploy countermeasures.

We performed the experiments in a lab environment where we simulated the ice conditions and observed the fluctuations in RSSI. Then we performed a correlation analysis on these two variables and presented the results in previous sections. The RFID sensors used in our experiments were Ultra- High Frequency (UHF) Gen-2 passive technology and the RFID reader used was a handheld type. Upon further funding, we will be able to perform experiments that will involve state and

federal highway agencies for us to plan and deploy our current system after performing pilot studies in more realistic environmental conditions.

Our research team at RAID Lab consists of highly talented graduate and undergraduate students from the University of Texas at Arlington who are mentored by academic scholars from around the world. The PI- Dr. Erick Jones is a pioneer in the RFID, Six Sigma and Supply Chain domains and has supervised several RFID deployments projects in both federal and state level. With a solid team, we are aiming for additional funding opportunities to continue our research to save lives by helping prevent accidents.

## 8. Future Scope

This technology will produce tremendous amount of data of real-time road conditions. We plan to integrate this RFID system with an Internet of Things (IoT) system that will automatically transfer the collected data to the highway authorities. The IoT system will comprise of transponders which will transmit information without human-to-human or human-to-machine interaction. The purpose of using this IoT system is to maintain a connected network of highway authorities, both internally and externally. By internal, we mean to connect stakeholders belonging to one authority since there may be different groups inside one entity such as planning, maintenance, safety, operations, etc. And by external, we refer to a connection of multiple divisions and state offices of the highway administration throughout the country.

RFID is larger and more diverse method of identification. All of the major Radio Frequency base identification systems have standards to which they are held to, and in IoT it is important to determine how large each is. The Ultra-High Frequency (UHF), RAIN, RFID standard has been by far the largest and most widely adopted standard. Companies such as Google, Intel, and Alien Technologies all embrace RAIN as the standard of the future for RFID. The RAIN initiative is attempting to bring RFID into the 21<sup>st</sup> century. RFID has been implemented by many companies, but the issue is that it is not exactly the same standard. RAIN hopes to fix this issue by creating a uniform group for all implementers of RFID in industry, so that products can be brought across facilities, companies, and even countries with no technical issues [15]. Our design will be

compliant to RAIN standards, especially since our long-term goal is to partner with state and federal agencies to deploy this throughout the country.

The next step in making the data even more secure and encrypted would be to put them in a blockchain ecosystem. Blockchain is an enabling technology which has seen rapid developments in recent times. It started out as the technology behind cryptocurrencies and has evolved over the years for applications in supply chain to prevent counterfeit products and provide provenance to commodities. Basically, it is a distributed network of computers which maintain blocks of information stored in them. The blocks contain transactions between stakeholders, contracts and other vital information pertaining to the commodity. As materials move throughout the supply chain, the blockchain is updated with real time information and is readily available to the stakeholders. The immutability and visibility of data in the blockchain ecosystem makes it an ideal technology for our project. This system would have the capability to securely display real time information to common people on demand. The IoT sensors would act as the enablers for transmitting data from the roads to the driver's smartphone in the form of an alert. This would require further investigation into the blockchain architecture design for this particular application and the compatibility of sensors in the blockchain ecosystem. We plan to design the software that would act as a middleware for the RFID system which would include algorithms for automated alerting during snowfall or blizzards. Our immediate focus is to apply for funding opportunities to explore these aspects of our work and partner with external stakeholders such as the Federal Highway Administration (FHWA) or state agencies for pilot studies and deployment.

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# APPENDIX

# **Equipment Data sheet**

# Details of Sensor:

# 1. Confidex Ironside Micro RFID Tag

On-metal tag with square inch foot print for various metal asset tracking applications. Due to small square inch (27 x 27mm) footprint Ironside Micro offers tracking solution for assets with limited a space for the tag. Ironside Micro is also available as HF/NFC variant. [11]

Туре	Dimensions	Memory	Read Range	Temperature	IP Rating
UHF RFID	27x27x5.5mm	128-bit EPC + 512 bit	Up to 5 m	-35°C to +85°C	IP68

# 2. HID Inline Tag

HID Global's Inline Tag<sup>™</sup> Ultra transponders are the most advanced general-purpose RAIN® UHF tags available. Choose from options that mount on any material while enabling read ranges of up to a 26 ft (8 m). Inline Tag Ultra RFID tags include HID Global's patented 3D antenna, enabling omnidirectional read range performance independent of mounting material. With the smallest footprint, the Mini version is ideal for tagging roll-cages, boxes, furniture or tools. They attach to any material, and deliver excellent size-to-performance ratios. [12]

Туре	Dimensions	Memory	Read Range	Temperature	IP Rating
UHF RFID	97x27x10mm	128-bit EPC + 512 bits	Up to 5 m	-40°C to +85°C	IP68

# 3. MetalCraft Universal RFID Asset Tag

Impact-resistant housing combined with an ultrasonically welded seal protects the subsurface printed label and RFID inlay from harsh environments including harmful UV rays. Affixing methods include mechanical fasteners (standard) and/or adhesive (optional). This revolutionary product line features surface independent tags with a patented inlay designed to obtain excellent read ranges regardless of the surface - metal, plastic or even wood. Custom programming matches the printed bar code information on the label allowing you the option of using both tracking technologies. Alien Higgs 3 chip optimized for use at 915 MHz[13]

Туре	Dimensions	Memory	Read Range	Temperature	IP Rating
UHF INLAY	104.77x44.45 mm	NA	Up to 7 m	$0^{\circ}$ C to + 71°C	NA

# 4. Intermec Asset RFID Tag

The IT36 is tuned for a wide frequency band between 860 to 960 MHz It include both FCC and ETSI regulatory environments and is optimized primarily for non-metal surfaces. The small, low profile IT36 is designed to provide superior performance and high durability on a variety of surfaces at a low cost. Typical applications: Returnable and reusable plastic containers (RPCs) including totes, bins, trays, and boxes; wood and plastic pallets. [14]

Туре	Dimensions	Memory	Read Range	Temperature	IP Rating
UHF INLAY	111.5x21.8x 5.1 mm	NA	Up to 11 m	-40°C to + 82.2°C	NA

## Details of Hand-held Reader:

# 1. MC3330R Long Range UHF Reader

The MC3330R RFID handheld reader brings a new level of comfort, speed, ease of use and accuracy to your RFID applications. Superior RFID read performance and receiver sensitivity enable lightning fast and accurate capture of even the most challenging RFID tags. With Zebra's signature rugged design, the MC3330R is built for maximum uptime, yet is lightweight with the right ergonomics for all-day comfort. And the large touchscreen, physical keypad and Android OS deliver an intuitive and flexible platform for your RFID application needs today and tomorrow. You get the signature rugged design of Zebra's industrial handheld products for maximum uptime. The MC3330R is one of the lightest devices in its class with the right ergonomics for all-day comfort. Superior RFID read performance and receiver sensitivity enable lightning fast capture of even the most challenging RFID tags. Workers can read both RFID tags and barcodes with point and shoot simplicity. [10]

Main Features:

• USB communication • Fast charge while using MC3300 PP+ batteries • Charges one device and one spare battery • Compatible with MC3200 and MC3300 batteries • Compatible with Level V and Level VI power supplies [10]

Туре	Dimensions	Memory	Read Range	Temperature	IP Rating
UHF INLAY	164 mm L x 75 mm W x 211 mm	4 GB	Approx. 19.7 ft.	-40°C to + 70°C	IP54

Display	Operating System	CPU	Frequency Range	Motion Sensors
4 inch Capacitive	Android 7.0 (Nougat)	Qualcomm 8056 1.8 GHz hexa- core 64-bit with power optimization	865-928MHz	3-axis accelerometer; gyroscope



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