U.S. Department of Transportation

Federal Highway Administration

FEASIBILITY STUDY OF RFID TECHNOLOGY FOR CONSTRUCTION LOAD TRACKING

Final Report

December 31, 2010

NOTICE

The Federal Highway Administration provides high-quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.

1. Report No. FHWA-OP-	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle FEASIBILITY STUDY OF RFID TECHNOLOGY FOR CONSTRUCTION LOAD TRACKING		5. Report Date December 31, 2010 6. Performing Organization Code
7. Author(s) Dr. Oliver Hedgepeth		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Alaska Anchorage College of Business and Public Policy/Department of Logistics Anchorage, Alaska 99508		10. Work Unit No. (TRAIS) 11. Contract or Grant No. AKDOTPF/AUTC PROJECT NO. C-08-01
12. Sponsoring Agency Name and Address Office of Transportation Management Federal Highway Administration 400 Seventh Street, S.W. Washington, D.C. 20590		13. Type of Report and Period Covered Final Report August 2009 – December 2010 14. Sponsoring Agency Code AKDOTPF/AUTC

15. Supplementary Notes

James Sweeney, AKDOTPF/ Billy Connor, AUTC, Contracting Officer's Technical Representative (COTR).
Technical report was performed under contract to C-08-01

16. Abstract

RFID technology was proven to be successful in tracking dump trucks from loading plant to a paver location on a highway project. The average roundtrip time was 1 hour and 4 minutes. However, 3% of this data has truck delivery times in excess of 2 hours, with two trucks more than 5 hours roundtrip time. There were approximately 16% data errors in zero data entry for roundtrip times. There were human errors in recording truck identification numbers and load type. The RFID recording technology appears to have worked properly. Human error at the weigh station can be eliminated by total automation. The requirements changes altered the approved SOW significantly; this should be taken into consideration for future RFPs.

17. Key Words Radio Frequency Identification Truck Asphalt Paving Construction Alaska	18. Distribution Statement

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 38	22. Price $90,000.

ACKNOWLEDGEMENTS

The author recognizes that support for this research was provided by a grant from the Alaska University Transportation Center in cooperation with Alaska Department of Transportation and Public Facilities, especially Jim Sweeney, for his oversight and counsel.

Steve Dombrowski and Trevor Edmondson, Granite Construction, for their willingness to participate in this study.

Curtis Kieres, and Dwayne McMurchy of MINDS, Inc., were instrumental in providing the hardware and field experience necessary to conduct this study. Their level of expertise was a key to the success of the project.

Mike Ronchetti, PMP, MBA, and Oran Weaver of Interviti, conducted the actual field work placing equipment on transportation assets used in this study. Their level of expertise in using the tracking technology was essential and the success of this project could not have occurred with his involvement.

Janet Burton, Administrative Assistance, Department of Logistics, College of Business and Public Policy, took photographs of transportation equipment displayed in this report.

Kathleen Ahern-Karnes, a graduate student Research Assistant, provided invaluable searches of current literature needed to balance the field data collection.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

This is the final report of a study in using radio frequency technology applications in the construction industry of Alaska. This report follows completion of actual field-work data collection, balanced by published industry literature as well as road construction documentation provided by the Alaska Department of Transportation (AKDOT). The essence of the report is to provide a framework for the implication of the use of a specific technology in road construction. This review of current published literature encompasses published works since 2005. This timeframe was chosen to represent the most recent changes in technology. Over the last five years there have been significant reductions in the size and cost of computer tracking technology. This technology shift has helped "better equipment scheduling, more efficient rating of transportation movements" (Coyle, Bardi & Novack, 2006, p. 6). The intent of this research was to document the use of technology. A determination of better equipment scheduling and more efficient rating of AKDOT and contracted carrier transportation is yet to be determined by AKDOT.

This project was a feasibility study, initially involving field work using a one truck pilot program; this was expanded later in the contract. The data collected should support the practicality, cost and modes of use of radio frequency identification (RFID) technology in construction operations.

The goal of this study was to demonstrate potential increases in profitability and operational efficiencies and decreases in labor, materials, and equipment costs.

The current tracking process uses a computer-generated ticket carried by the truck driver to the dump point. The truck driver initially receives a cargo ticket while loading. The load weight is recorded on the ticket at a plant weigh scale. At the dump point, the ticket is handed to a ticket taker on the grade. The ticket taker records additional information on the ticket, such as the time and the station of the dump point. There are at least four people who handle this cargo tracking ticket: a truck driver, scale person, ticker taker, and an office person. A driver must maintain possession of the ticket at all times during cargo or load transportation, according to state and federal regulations. A scale person updates this ticket. A ticket taker at the end records the final data. An office person tallies the day's tickets to create an account payable item (payment) to the carrier or driver. These tracking tickets must be physically stored for three years after project date of completion.

RFID technology was proposed to be used to track or record the same data. A schematic of this field testing of RFID placed on one truck is shown in Figure 1.1. Initially, the assumption was that one field agent was to be used to record the loading and dumping of each truck using a handheld, portable RFID reader. And, it was assumed that an active RFID tag would temporarily placed in the cab of the truck. However, the reality of the fields exercise changed these earlier assumptions.

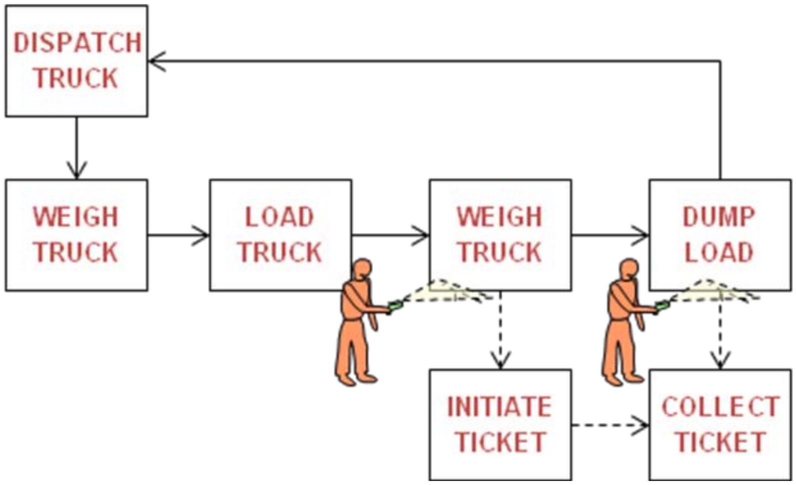

Figure 1.1: Initial schematic of possible supply chain check points and RFID reader positions.

The benefit of this study was to answer the question: What will this technology contribute to measurably improve quality control compared to the current manual data collection process? The answer is yes, but there are constraints.

1.1 Problem Statement

The problem was that there was no real-time inventory capture of data. There was no real-time communications of this data capture. The current process is manually receiving and recording carrier and shipping and load data.

RFID is not a new technology. RFID is a sixty-year old technology that recently miniaturized the computer chip needed to receive and transmit an radio frequency (RF) data signal to the size of a grain of pepper with similar decrease in cost. RFID technology allows accurate and timely recording of data from tractor trailer or straight trucks delivering goods using hands-free radio frequency transmission technology. The goal of this research project was to determine if RFID technology could significantly contribute to improve quality control of compared to the current manual data collection process.

1.2 Problem Background

The AKDOT and AUTC has an obligation to examine its business practices and processes to determine if there are methods that are more efficient or process changes that could be adopted to increase the rate of product flow to a work site, optimize manpower, and minimize costs. The current method of tracking and tracing truckloads of construction materials from a source to a work site involves several stops for weighing, as well as several manual process steps to record truck and cargo flow data. While the current "as is" process works, AKDOT and

AUTC considers that several manual data capture steps can be automated. The saving would be measured in terms of the number of truckloads delivered per hour, per 12-hour shift, and each 24 hours. At least this was the initial metric used before field testing of the equipment.

The study results can be measured in the number of truckloads delivered in 24 hours, number of human errors in data capture; cost of transportation to include fuel to the carrier, amount of time driver is behind the wheel, improved worker safety, possible lower contract bids by vendors, and decreased costs to the State of Alaska. The actual measurements were in time and distance of truck routes in a closed-loop pick-up and work site delivery event.

This study did demonstrate a potential process change using new tools and technologies. Such changes could impact new project planning, management, and tracking of transportation operational data.

1.3 Study Objectives

The objective of this study was to assist in the documentation of unit price pay items, such as asphalt, base course, borrow and riprap, used in the road construction business practice and process. These are items commonly tracked from the source, such as a pit or plant scale to a construction site.

The current tracking process uses a computer-generated ticket carried by the truck driver to the dump point. The truck driver initially receives a cargo ticket while loading. The load weight is recorded on the ticket at a plant weigh scale. At the dump point, the ticket is handed to a ticket taker on the grade. The ticket taker records additional information on the ticket, such as the time and the station of the dump point. There are at least four people who handle this cargo tracking ticket: a truck driver, scale person, ticker taker, and an office person. A driver must maintain possession of the ticket at all times during cargo or load transportation, according to state and federal regulations. A scale person updates this ticket. A ticket taker at the end records the final data. An office person tallies the day’s tickets to create an account payable item (payment) to the carrier or driver. These tracking tickets must be physically stored for three years after project date of completion. Technologies such as RFID and GPS can be used to track or record the same data.

The objective of this study was to develop meaningful case scenarios for the demonstration program to test/demonstrate a particular RFID tool or phase of the project. University of Alaska Anchorage (UAA) used its expertise in RFID, project management, and logistics management to analyze the “as is” and “to be” processes, to assist in the development of scenarios and test cases, and to assist in the evaluation of processes, procedures, tools, communications and computer systems, and related technologies that are integrated into the demonstration environment.

CHAPTER 2. BACKGROUND

The RFID system consists of a tag, which is made of a microchip with a coiled antenna. This tag was placed on the side of a truck. This tag communicates with an interrogator or reader, which also has an antenna. The reader transmits electromagnetic waves that form a magnetic field, which activates the antenna on the RFID tag. A passive RFID tag draws power from this magnetic field and uses it to power the microchip's circuits. The chip then modulates the waves that the tag then sends back to the reader and the reader converts the new waves into digital data. The reader interprets the tag data and communicates this data to a computer. There is also computer middleware, which is used to process large amounts of data. This data is then stored in a computer memory for processing or interface with other software inventory systems or analysis systems. RFID uses the low-end of the electromagnetic spectrum. The waves coming from readers are no more dangerous than the waves coming to your car radio. (Hedgepeth, 2007)

RFID tags are either active or passive. The active tags can be considered transmitter tags. They have been around since the 1940s. Active tags have a battery for a source of power to store data or to transmit a radio signal with the data. As such they act just like your portable radio and can be read over a great distance with a limit of about 100 feet or 30 meters. Active tags are usually very costly. The active tag is usually encased in a hard shell for protection, since these tags are used in rugged environments. These active tags are used for a variety of purposes, such as tracking the time and temperature of hot-mix asphalt such as for this study.. (Hedgepeth, 2007)

Other active tags might be attached to boxes of cargo destined for a war zone for the military and needs to be able to withstand pressure, extremes of temperature and shock. The cost of active tags varies but ranges from about $30 to more than $100. (Hedgepeth, 2007)

The passive tag can also be encased in a hard plastic shell. The passive tag has no battery. The micro-chip is about the size of a grain of pepper and is usually at the center of an antenna array. This chip receives energy from the reader, which also transmits a signal, described earlier. The power of the passive tag comes from the conversion of the RF power into a DC current. The passive tag needs to be closer to the reader than the active tag. Experiments and operations usage indicates that placing a reader within about five to eight feet is sufficient to produce the required data transfer. However, they can be closer. On occasion readers have been successful out to 30 feet, but these are in laboratory conditions. (Hedgepeth, 2007)

There are university laboratory and field tests that have been conducted as well as commercial companies ready to develop and apply their RFID expertise to this transportation problem. One such company that appears to have significant experience in tracking asphalt deliveries is Minds, Inc. (2010). This literature search is not endorsing the Minds, Inc. technology. There a many different companies that can engineer specific RFID technology capabilities for such field exercises (Ross, Burns, Wu, and Jarad, 2009; Hedgepeth, 2007). The scope of this test however dictates seeking a low cost alternative with significant past application in asphalt pavement developments. Minds, Inc. is still considered for the purposes of the field test the most applicable for the short timeframe of this study.

CHAPTER 3. RFID METRICS

This field work should have provided data collection and analysis to refine a methodology for this asphalt tracking process that addresses project needs for information collection instruments. An approved data collection methodology was developed at the time of field implementation of the RFID technology.

One of the first steps for such a study is in defining the analysis problem is to understand the environment of AKDOT's current asphalt trucking and logistics billing and inventory record-keeping requirements as an "as-is" process. Figure 1.1 shows a simplified overview of this environment as a multi-step process that was the original design for data capture. The RFID data collection points in Figure 1.1 are notional and did require actual field work to determine final placement for data collection.

Within the above context, three questions and related hypotheses form a problem statement for this field evaluation are defined as an analysis problem statement and related hypothesis statement.

3.1 Analysis Problem Statement 1: How are the asphalt truck ticket capture and filling accuracy rates affected by the introduction of RFID tracking system? The related hypotheses are:

A. **Hypothesis One (H_1):** The current manual (paper based) truck ticket tracking accuracy (MTA) rate is equal to the RFID tracking accuracy (RTA) rate.

$$\mathbf{H_1: MTA = RTA}$$

This metric will show how the accuracy rate of each truck driver ticket for each delivery during a day (by ticket document number, or some other label) by each truck driver or different trucks used in the field test. This equates to the accuracy of the same ticket data capture method using RFID technology over the specified time of the field tests. The metric will be in numbers of tickets that are classified as not accurate. The goal of this hypothesis is to reach a point where the numbers of miss classifications are equal with both manual and RFID-based inventory and billing tracking methodologies. Figure 3.1 shows how such a difference between the two metrics, MTA and RTA, could greater than 10% we can say that there is a significant difference. If the difference is less than 10% it is not significant. For example, if MTA is 350 driver tickets identified with 35 inaccuracies, and the RTA shows 633 requisitions with 33 inaccuracies, then we could show in Figure 3.1.

	Total Truck Tickets	# Accurate	# Inaccurate (%)
MTA	350	315	35 (10%)
RTA	633	600	33 (5%)
Difference	283 (350/633=55%)	NA	2 (33/35=94%)

Figure 3.1. Capture Rate of Truck Driver Tickets compared to Accuracy Rate

Given this information we could conclude that this hypothesis shows that MTA ≠ RTA as an absolute number (that is, 34 ≠ 33). But does this inequality hold for percentage differences? The answer may be no. This is due to the number of inaccurate differences being 2 or 6% (100%-94%) in this example, which is less than 10%.We could conclude from the percentage differences that H_1 is true and that MTA = RTA.

While the total number of driver tickets captured shows a 55% difference, this number is only useful for administrative purposes at this time. The difference in number of accurate driver tickets is meaningless in this hypothesis. However, the overall numbers of truck tickets that are inaccurate still needs to be addressed so as to make this number approach zero %.

B. **Hypothesis Two (H_2):** The manually processed truck ticket accuracy rate demographic (MRAD) for two-level factors are the same.

$$H_2: MRAD_1 = MRAD_2$$

The metric used for this hypothesis is that the demographic designation for the different type of drivers, weight station employees, or AKDOT employees manually processing or filling truck tickets. For example, the number of truck tickets being filed by two different drivers or using two different trucks are one group, $MRAD_1$, could be significantly different (in accuracy) from another driver or truck at a different or even the same construction location, $MRAD_2$ .The two-level factor would then be accuracy rates of different types of drivers or trucks used. Similar demographic information at two levels could possibly be used, such as class of materials carried in construction trucks, such as asphalt compared to gravel, or as a contracted service, such as one construction company compared to an alternate construction company. Absolute numbers and percentage differences as shown for solving the analysis problem statement one would be used.

3.2 Analysis Problem Statement 2**:** What is the probability of finding an accurate match using both manual driver ticket collection method compared to RFID method. The related hypotheses are:

Hypothesis Three (H_3): The probability of manual truck driver controlled ticket processing or filing (MF) is equal to the probability of RFID (RF) ticket processing or filing:

$$H_3: P(MF) = P(RF)$$

Inaccurate data can cause the truck or driver tracking system to be inefficient. The metric for testing this hypothesis is based on an assessment of a baseline of manual truck driver tickets filed accurately with AKDOT over a period of time by a set number of drivers or construction companies at various nodes along the construction site supply chain. The probability of finding either a correct or incorrectly classified truck driver ticket is defined as a Bernoulli process, which follows a Binomial distribution. This probability can be defined on a monthly (or daily) basis and evaluated constantly during the test period. The final results of this study will provide a probability statement with a specified and measured level of confidence.

The literature review identified possible others variables that could be used in this study or follow-on studies.

3.3 Research Methods

This is a quantitative research design compared to a qualitative research design (Creswell, 2009). As a quantitative study, the metrics are designed to capture measureable or countable relationships among all the variables. (Creswell, 2009, p. 4) The measurement instruments were to be paper copies of truck driver tickets and spreadsheets in some automated format using software such as Excel. The data that is therefore collected must be instrument based, performance data, and observational data. Statistical analysis was conducted on all data collected for statistical interpretation (Creswell, 2009). The metrics have been formed as a basis of theories concerning the differences between a manual method and the RFID method of collecting operational data. The result should form an unbiased approach to answering the questions of this study.

Research design is a plan for conceptualizing the structure of the different variables that are studies as RFID technology is evaluated for AKDOT use. It implies how this research situation can be controlled, and how the AKDOT data is to be measured and analyzed. The research methodology indicates how to take observations in a systematic and standard manner. This researcher evaluates and compares the capture and accuracy rates among the current manual and RFID being examined and tracked over time. This evaluation requires specification of the data models, the data stratification strategy for the building and testing of these data models, and a logic for assessing performance of these models.

3.4 Assumptions

There are several initial assumptions from early literature review needed for statistical analysis of the data produced from the data to be collected from this study.

- AKDOT field data is captured with a normal probability distribution.
- Errors in one AKDOT database are independent of errors in any other database.
- AKDOT manual and automated data and files are not damaged or altered prior to study team having accessibility.
- The data capture technology for RFID records do not fail and event records are uniquely identified.

- The probability of each RFID and manual data record being correct in any database is the same.
- The AKDOT and other construction professionals do not make mistakes when checking or providing the study team data or access to trucks, pavers or other equipment.

These assumptions provide a part of the initial basis for measuring this study's analytical problem statements and hypothesis. Some of these assumptions were violated resulting in an evaluation problem or issue.

CHAPTER 4. LITERATURE REVIEW

This literature review is meant to “provide insight into ways in which the researcher can limit the scope” of this study. (Creswell, 2009, p. 23) It examined published documentation on the use of RFID tags focused on the studies problem examining the road construction industry, specifically the use of asphalt truck tracking. The literature review is created to bridge any gaps between what is expected within the scope and problem definition of this study and any similar studies, or comparative studies. (Creswell, 2009, p. 25) The time horizon for the most of the documents review is since January 2005. Due to the significant increase in interest in the use of RFID technology for tracking and tracing vehicles and goods, it is expected that any published reports prior to 2005 would provide insufficient information or data.

The references listed are not all fully investigated. Only the top tier have been reviewed with regard to the technology.

4.1 High Temperature Testing

Ross, Burns, Wu, and Jarad (2009) conducted testing of passive RFID (Hedgepeth, 2007) tags in a laboratory environment. Part of the scope of their work was to simulate the harsh conditions expected in the field that might use such RFID tags in the future. They also preformed chain-of-custody tracking and tracing of items within a testing facility, a building (p.3). The RFID tags used were from a variety of vendors, such as PSC, Think Magic, Motorola and SATO (p. 4). The construction material used with such tags was “reinforcement steel, geosynthetics, and concrete cylinders” (p. 4). RFID tags were subjected to harsh field conditions simulated in a laboratory. These conditions include immersion in water, acid, base solutions, pressure testing, freeze and thaw, and extreme temperature. (pp. 5-6) The extreme temperature test consisted of placing the RFID tags “into a paper cup inside the oven at 100ºC (212ºF) for a prolonged period of time” (p. 8). The read range of these tags was a constant distance once they were taken from the oven. The result was that “the read range for tags subjected to extremely high temperatures tended to decrease with time” (p. 8). The read range varies from approximately 17 feet between the RFID tag and the reader, and about seven feet. (p. 8) The seven foot distance resulted only after exposure to a temperature of “250ºC (482ºF)” (p. 8). The conclusions reached by this laboratory testing were “that RFID tracking technology is a viable option for monitoring the progress of construction material samples within a high-volume testing laboratory” (p. 8). These tests were not conducted in the field but totally in a laboratory. Further conclusions were that “RFID tags performed well under a series of harsh environmental conditions” (p. 8).

4.2 Asphalt Paving

Kilpellainen, Heikkilam, and Parkkila (2007) conducted field research on “asphalt mass, transportation of the mass to the work site, asphalt laying and compacting” (p. 35). This was a qualitative research design (Creswell, 2009) consisting of interviews with construction professionals (p. 36), plus a quantitative research design tracking variables such as, “weather, traffic conditions, failures of the machines, the number of trucks available and transportation distance" (p. 36). The construction consisted of a mobile asphalt mixing plant with distances from the paving construction site would be within 100 km (62 m). (p. 36). This distance for delivery became a key factor in the process analysis of paving. Thus, a key factor in the analysis by Kilpellainen, Heikkila, and Parkkila (2007) was the need to "asphalt production, transportation, spreading and compacting" (p. 36) to work seamlessly. The asphalt loading temperature was note to "be lower than 150ºC (302ºF)" (p. 38). This was not a test of RFID technology however. It was one of using other wireless communications devices, such as the cell phone, to report needed measurement data, and embedded temperature sensors with long range data transmission devices. (p. 38) However, "one of the disadvantages discovered is that the system is totally dependent of the users" (p. 37). This qualitative aspect of the research introduces the possibility of human error. The use of cell or mobile phones was useful to communicate acidity as the work site. However, these wireless devices were not connected to temperature of other environmental or paving data collecting devices. (p. 37) Kilpellainen, Heikkila, and Parkkila (2007) also indicate that the metrics to be captured for a complete supply route of one asphalt truck should include times for loading, transportation, waiting, unloading, returning, and waiting for loading. (p. 37). All times are in minutes. Two other metric and variables are transportation distance and the amount of asphalt mass transported. (p. 37) This research did indicate the different types of professional at the work site that could be interviewed if a qualitative research is needed for this current project. There would be work supervisor, asphalt mixing plant operator, asphalt paver operator and truck drivers. (p. 37)

4.3 RF Signal and Data Accuracy

Lee, Song, Kwon, Chin, Choi, and Kim (2008) developed an RFID "gate sensor for real-time delivery status monitoring" (p. 101) of construction trucks entering and leaving a work site. While their field testing indicated that RFID signals could be read from a truck entering a fixed gate position, it was found that the physical placement of the antenna and RFID tag could "affect the recognition rate" (p. 105) of the signal.

Lee, McCullouch (2007) conducted an study to automate the manual tracking of truck tickets using bar codes instead of RFID tags. While the technology is different in many ways (Hedgepeth, 2007), the process of going from a manual system of collecting data from construction trucks to an automated system was comparable. One of the lessons from this was one additional potential data capture variable, the "driver and customer signature capture" (p. 11).

Lee, McCullouch (2007) also conducted a sampling of different Departments of Transportation's capabilities with manual tracking of trucks for material delivery to construction sites. Their study indicated that "only two states, Louisiana and New Jersey" (p. 22) had an automated system to track the delivery of construction materials from pick up point to construction site. Other states contacted indicated a manual or paper delivery system or use of field laptops for data dumping using the Internet. (p. 23) When Lee and McCullouch asked different states about the need for automated tracking of trucks, "41% answered that they need an automated delivery tracking system" (p. 25). Of course, that 41% could be a bit misleading as they contacted only seven states. (p. 25) Their final conclusion from their qualitative and quantitative study was that an “automated materials delivery records system will potentially be beneficial to all the project parties from material suppliers, trucking companies, contractors to the state” (p. 44).

Fedrowitz (2007) analyzed the use of RFID technology for Virginia DOT for a highway maintenance project. Their research indicated that the reading of construction trucks from a parked position and moving at 10 mph could be read at a distance of 115 feet. (p. 43) They also examined the capability of attaching fixed antennas to metal mile marker signs with trucks traveling a variety of speeds from 10 to 65 mph. The distance from the readers varied from 5 to 100 feet. (p. 34) Various antennas sizes were also employed in this field test.

Arrington (2009) examined the accuracy issues of the research conducted by Fedrowitz (2007). One of the findings was that, “the performance of RFID systems are adversely affected by water or wet surface” (p. 16). Field testing indicated that RFID “tags count not be placed directly onto the metal mile marker sign” (p. 16). As for the rate of RFID tags data to be read by an antenna, this research indicated that the RFID “can handle 100 reads per second” (p. 17). While the field testing appears to have shown value in the use of RFID technology there was still needed “some method of ensuring data integrity” (p. 71).

Wyld (2005) was one of the early supporters of RFID technology for government projects. A wide range of applications was evaluated. The results were more positive than negative for the accuracy and value of the use of RFID technology.

Almanza, Hernandez-Gutierrez, and Ibarra-Manzano (2006) analyzed vehicle and driver crossing a gate or threshold using RFID technology. While this was not part of road construction efforts, it did point out the accuracy features for RFID technology. One is the lesson learned was that “when a system is implemented with passive RFID tags…range is highly dependent on antenna orientation because readers and tags must be magnetically coupled in order to communicate” (p. 225). This relates to the placement of similar RFID systems on the metal surface of this current studies trucks and field testing of position location of the RFID tag on the truck body, or paver body.

Khan, Akhtar, and Qadeer (2009) bring up an interesting point that is often overlooked in programs to use RFID technology. They found that “only 23% of consumers have heard of RFID” (p. 334). The authors of this current study have also had antidotal evidence from military and retail sources that indicates a high percentage of workers today do not know of RFID technology or how it compares to bar codes. This could be an issue for data capture and data accuracy is workers in the field are not properly trained on what the RFID tags is placed on a construction truck and how the antenna has sensitivity to physical placement on different objects.

Ergen and Akinci (2009) evaluated RFID for the construction industry in general. They indicate that the “construction industry mostly has dynamic and uncontrollable environments where tracking and locating materials and accessing related information is challenging” (p. 5). They also find that while RFID technology is successful in this industry, that “limitations of the current technology can be overcome by using some reasoning mechanisms that are developed and implemented for data cleaning and processing purposes” (p. 5). This data accuracy and data mining of the captured data is one of the emerging trends or issues in the use of RFID (Hedgepeth, 2007).

Lim and Koh (2009) conducted studies to also examine what they termed as organizational fit for the use of RFID technology. Their results indicate a higher level of matching the organizational values and objectives to the use of RFID. This suggests again that possible human errors could increase if the workers within the organization are not properly trained to understand the implications of using RFID technology.

El-Omari and Moselhi (2009) analyzed how to organize and store data collected from RFID systems. They indicate that the applying tags “in the construction industry is hampered by the rough conditions of site operations that may damage barcode tags” (p. 493). They find that “RFID was introduced to overcome barcode drawbacks” (p. 493).

Closely aligned to the accuracy of RFID signals is the standardization of the functionality of the tags. Engels and Sarma (2005) highlight a potential problem with “vendor specific functionality” (p. 5) in the use of RFID tags. This is an old warning in this technology since the surge in 2005 (Hedgepeth, 2007), but the warning bears paying attention to. If the functional data capture of tags in the construction industry is not standard in its data capture protocols this could cause some issue with communicating the results to other in the similar construction industry.

Wang (2007) indicates that construction companies “began to examine the use of barcodes for tool management in the early 1990s” (p. 469). So, that construction companies not new to using automated methods of data capture compared to the manual methods. However, as in previous research the barcode has been found to have “problems in the construction industry due to the short and long range and poor durability” (p. 469). The barcode “becomes unreadable when scratched or dirty” (p. 469). The implication is again that RFID technology with it is non-line-of-sight capability provides better data capture and accuracy than barcodes. (Hedegpeth, 2007; Wang, 2007)

Song, Haas, and Caldas (2006) found that levels of power for the RFID tags are a consideration if they are to work properly in the construction industry. (p. 914) They also developed metrics for data collection. Their metrics were “the maximum number [sic] of reads that can be contribute to each … set of proximity information” (p. 915). Additional they measured the number of tags, pattern of placement and number of data reads. (p. 915) Their results indicated that power is a key factor to the tag location. They found that “approximately 68% of the experiments when the medium rf power is in use” (p. 916). This indicates that when this current study uses RFID tags that there may be an issue of the level of power to use. This current field study could possibly use two ranges of power, medium and high, if there were time. But, this may not be the case for such a short study. One of the conclusions of their study goes beyond the scope of this current research study, but should be considered for the final report and decision making. That is that, “although economic considerations were factored into the development…potential economic feasibility should be estimated to justify up-front cost of implementation” (p. 917). This is indeed the case, and Newnan, Lavelle, and Eschenbach (2009) provide a foundation for RFID calculations for future worth calculations.

4.4 Current Applications Viewpoint

This is an event-management exercise. An event is defined for this experiment as each point along the roundtrip of the truck picking up and delivery of asphalt. Each point of stopping by the truck is an event. And, as is common in the study of supply chains, there is an event of delay. How much time is deemed as a delay is part of the data collection and not as readily known prior to the experiment's conclusion. So, there are two categories of events: pre and post-experiment.

While this is a single-application description of RFID usage, the potential end result for strategic planning is for a net-work application. This experiment is considered a single application due to the closed loop system described by the geographic constraints defined by the truck routes of load pickup, load delivery and return for a new pickup event. Therefore, this is a closed-loop, single-application series of events.

The results of this experiment can be used as a benchmark. However, the results are not to be construed as a set of best practices; not yet. This benchmark is part of that process.

While many applications of the passive or active tags for tracking trucks attach the tags to the rear of the chassis, this experiment attached the tags onto the outside of the truck bed. Also, many applications use a fixed reader of antenna loops located under the road surface to track trucks entering a specific lane at a gated entrance. The application used in this experiment used a mobile antenna design. Even though mobile in application, the RFID tags and readers still discriminate between trucks in the virtual gate lane at the construction site (Wessel, 2009, para. 3).

Similar to Wessel (2009), the use of RFID tags for tracking truckloads of asphalt creates a license plate for a multi-step virtual gate data capture and transactions (para. 6).

Wessel (2009) found that replacing the manual, paper-based ticket or instructions for their truck tracking applications with RFID, "saves an average of 10 minutes per inbound and outbound load" (para. 10).

Swedberg (2010) reports on , use of RFID tags, "to track the amount of coal being loaded onto trucks" (para. 1). The results indicate that "wait times are reduced and billing is more accurate, based on automating what was previously a labor-intensive system of tracking the weights of trucks and the coal loaded within them (para. 1). While this is not identical to this asphalt research experiment, the tracking of truck from loading to dump side, through a weigh station, is identical. The metrics savings reported that "the system has reduced the operation time of weighbridge employees by 30 to 40 percent" (para. 1).

Swedberg (2010) indicates that the automated system combines the RFID tag identifier along with the truck's license plate number to verify the truck. The license plate is recorded by the weigh station person by manual or video capture (para. 6).

The use of RFID has not replaced the manual process. Swedberg (2010) reports that “The truck driver hands the weighbridge staff the loading document, which the employees can compare against information on the PC” (para. 6).

Kilpelamen, P., Heikkila, R. and Parkkila, T. (2007) conducted a comprehensive test of RFID technology for tracking and tracing the routes of trucks delivering asphalt to road construction sites. They had a comprehensive list of variables to track truck loading of loading time, transportation time, waiting time for unloading, unloading time, returning time, waiting time for loading, transportation distance and amount of transported asphalt mass (p. 27). Their experiment was to start with a baseline of theoretical data for each variable, such as making the assumption that waiting times are zero and truck loads of asphalt of maximum load capacity.

Ross, Burns, Wu, and Jarad (2009) did demonstrate in a control laboratory environment that RFID tags could maintain an operational read range from seven to 17 feet when exposed to high temperature in an oven, but taken out of the oven for reading measurements. Depending on the distance considerations for the field testing of this current research project, the results indicate that read range for passive tags should include a distance not to excel 17 feet. However, this is not a conclusive or exhaustive test result. And, the tests performed on passive tag and not the battery assisted active RFID tags. (Hedgepeth, 2007)

When examining the distance from the asphalt mixing plant and the construction worksite, the example from Kilpellainen, Heikkil, and Parkkila (2007) indicates that about 62 miles is a workable distance for hot-mix asphalt. The scheduling of truck movement from their experiment compared to a potential field exercise in Anchorage, Alaska indicates that the distance metric between asphalt mixing plant and the work site should not be a factor in the cooling of the hot-mix asphalt load in truck. While the process did rely on wireless communications, this was still a manual process of data collecting and reporting. The reports would be considered immediate between sender and receiver, not having to wait on a paper trail from a truck driver. From their research we can determine that the stakeholders for the current research project should be at least work supervisor, asphalt mixing plant operator, asphalt paver operator and truck drivers. However, in this current research design, we have included weight scale operator and AKDOT analysts processing the daily truck tickets.

The data capture and accuracy are an essential part of the emerging results from RFID studies. It is apparent that the focus is changing to data capture accuracy and eliminating automated data capture errors. Just going from a manual process to an automated one with RFID does not ensure 100% data capture.

4.4 Performance Variables

The initial metrics of this study were based on a comparison of a current manual process of tracking and tracing the complete cycle of asphalt paving compared to an expected automated process using RFID technology. The metrics for the initial scope of this effort are listed in the Chapter 2: Background. However, these metrics were modified based on the field conditions and further analysis and discussion of the metrics used in previous studies reported in this literature review.

It is possible that the range of metrics could have included:

- Tracking data accuracy
- Asphalt loading time per truck
- Truck transportation time
- Truck and driver waiting time
- Truck unloading time for asphalt
- Truck return time for a new load of asphalt
- Truck waiting time to load asphalt mass
- Truck driver signature capture time
- Asphalt temperature during loading and unloading

CHAPTER 5. FINDINGS

5.1 Setting the stage

This experiment was conducted in the field from June 30 to July 17, 2010. AKDOT was conducting resurfacing on the Glenn Highway. The RFID product used was PaveTag™ supplied by MINDS, Inc. The location of this study was Anchorage, Alaska. The AKDOT contracted to Granite Construction of Anchorage, Alaska to provide the required amount of asphalt for the road construction project used in this study. Figure 5.1 shows the Granite Asphalt Scale in Anchorage that was used as one event point.

Figure 5.1: Granite scale in Anchorage with stationary pole and RFID reader/antenna in the foreground. The PaveTag™ processing hardware is the gray box sitting on top of the concrete support, next to the antenna pole. Photo by Janet Burton, University of Alaska.

This scale was at the Dowling Road location in Anchorage. You can see the PaveTag reader was located on a stationary pole in the lower right of this photo. Not shown, was a printer that was located in the scale house. When each read occurred the data signal from the scale-house computer was transmitted using MIND, Inc, eRoutes™ software.

The actual RFID tag was located on the rear of each truck as shown in Figure 5.2. These ten RFID tags were attached using adhesive and molding tape and self-tapping metal screws. Since weather was not a factor and this project was only a few days in duration, more permanent fasteners was deemed not necessary. If this were in an Alaska winter environment, other fasteners would be considered.

Figure 5.2: RFID tag mounted to the left of the license plate.

A photo of the stationary asphalt plant used in this study is shown in Figure 5.3.

Figure 5.3: Stationary asphalt plant off Dowling Road in Anchorage, showing truck loading to the far right. Photo by Janet Burton, University of Alaska.

The initial requirement for this study was for one dump truck. However, in the field, it was decided by AKDOT to use ten belly dump trucks. Figure 5.1 shows one of these ten trucks.

A paver was also used, but had not been part of the original study design. Again, this addition was made as a requirements change in the field by AKDOT. A photo of the paver used as part of this study is shown in Figure 5.4. This photo shows Mike Ronchetti installing a complex system of RFID, PC, GPS, and WiFi transmitter.

Figure 5.4: Construction paver, CAT AT-1055. Mike Ronchetti is attaching an RF reader. Photo by Janet Burton, University of Alaska.

5.2 Data Collection

The data collected is located in a separate file, PaveTag RFID Data Report. The data items selected to collect were based on experience from MINDS, Inc. rather than this SOW for this project.

The list of data items collected was as follows:

- The truck ticket number.
- The customer name on each ticket.
- The identification number for each truck.
- The net weight of each truck measured in US tons
- The construction plant identifier.
- The date and time the truck was recorded entering the plant.
- The date and time the truck was recorded initially by the PaveTag™.
- The date and time to load the truck.
- The date and time by RFID read that the truck exited the plant.
- The amount of time that the truck stayed in the plant as read by RFID.
- The paver identification used in this study.

- The date and time when the dump truck was close enough to be read by the Paver RFID system.
- The date and time that the dump truck dumped its load in the paver.
- The date and time that the dump truck was leaving the paver location.
- The date and time when the paver could no longer indicate the truck was in its area.
- The total time of each truck on the construction site recorded by the paver.
- The total time of each round trip made by each truck.
- The job identification number that was on each ticket.
- The GPS latitude and longitude of the paver when the trucks were first recorded.

While this set of data sufficient, not all data items were recorded. And, several time items were entered as zeros.

An initial examination and plotting of the raw data for round trip time of each dump truck indicated some surprises of missing data; recorded as zero. The raw data is plotted as shown in Figure 5.2.1.

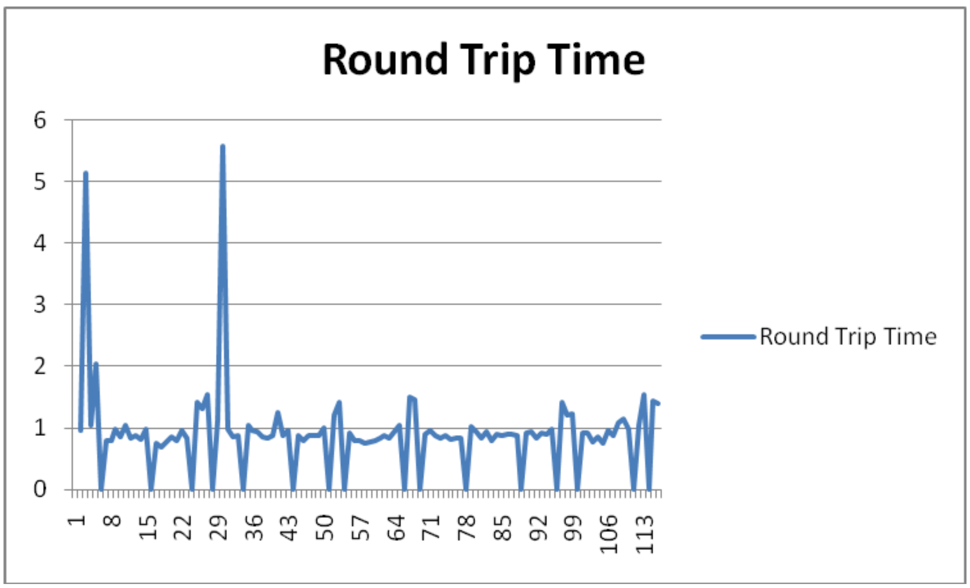

Figure 5.2.1: The raw data for round trips made by each truck plotted as time of the vertical axis and number of truck deliveries on the horizontal axis.

The initial examination of this data shows 16 zero data entries. These will be taken out of the data analysis in the next filtering of the data.

But also note that two trucks had round trip data recorded as more than five hours. The decision to leave these two data points in for analysis of roundtrip data is up to the decision maker and the statistician. As raw data, zero entries can be removed from the data field. But for now, the two data points greater than five hours will be left in. Doing so produces Figure 5.2.2

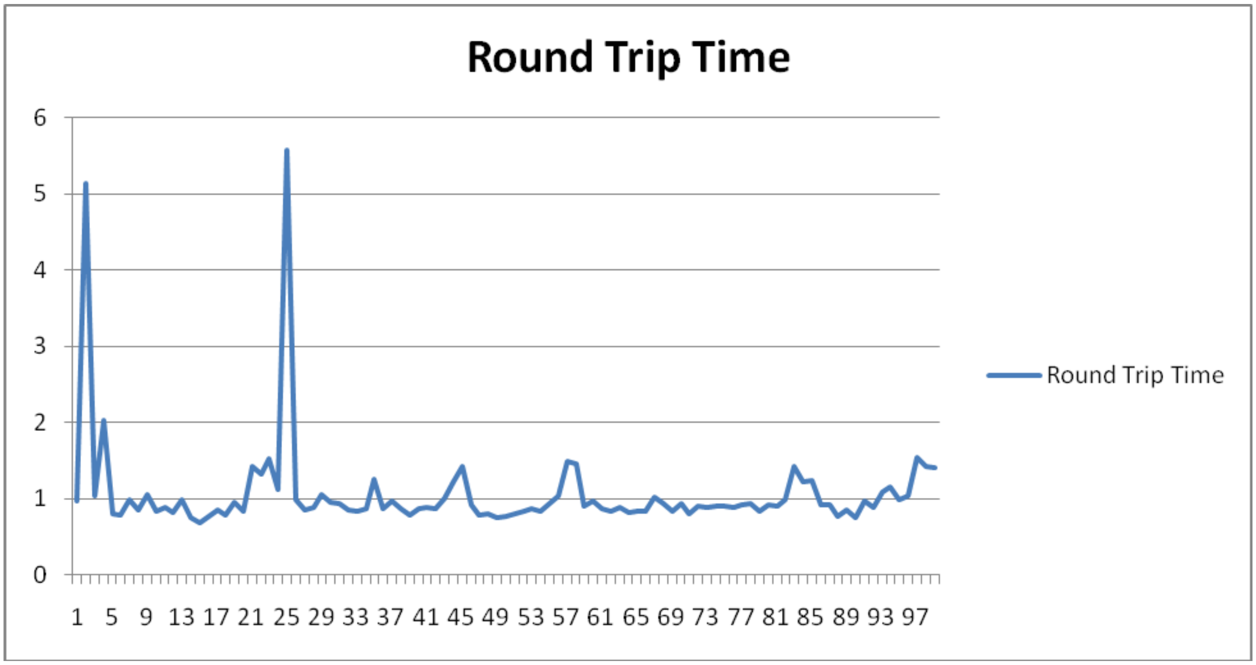

Figure 5.2.2: The raw data scrubbed of all zeros for round trips made by each truck plotted as time of the vertical axis and number of truck deliveries on the horizontal axis.

Figure 5.2.2 now shows a range of times that the dump trucks make between the Dowling Street location and the Glenn Highway construction site. The location is approximately one hour total time (1 hour and 4 minutes), which includes dumping the asphalt. This analysis now shows that there are three anomalies. One truck load took almost two hours along with the other two trucks taking over five hours between pick up and dump sites. One other data point of interest is the time the trucks remain at the plant while loading. That time is shown in Figure 5.2.3.

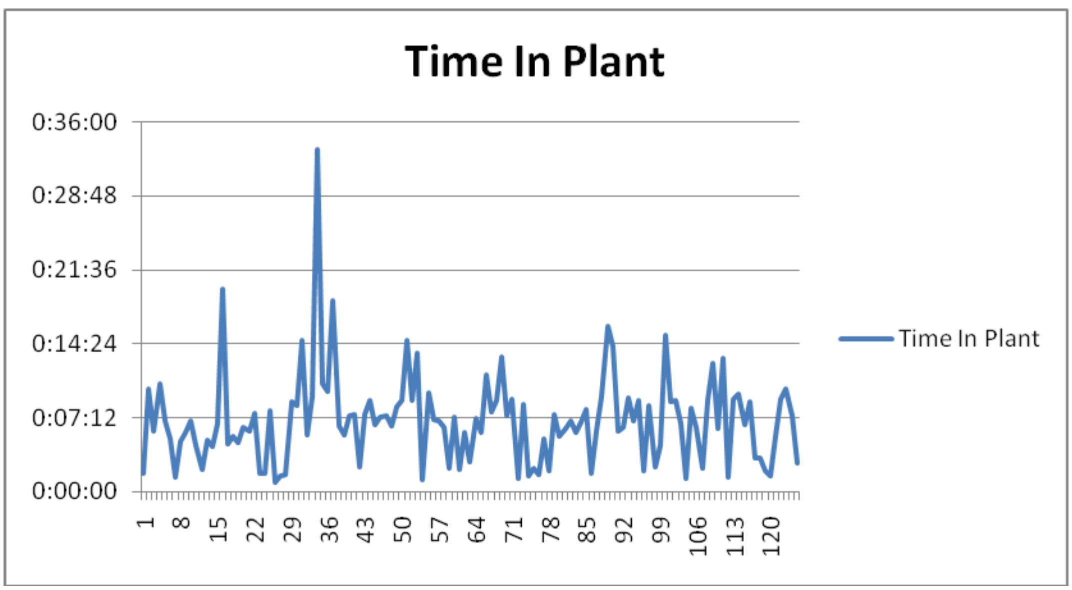

Figure 5.2.3: The raw data for the time each truck stays at the asphalt plant measured in minutes and seconds.

This data shows that each truck stays in the plant for a range of a few minutes to approximately 15 minutes.

5.3 Data Issues

It was found that scrubbing of data had to take place to produce a clean set for analysis. However, this report only modified these data items as indicated above. It was reported that there were some human operator errors of a few tickets related to the job identification number and the type of material. The later is interesting since the material being tracked was only one kind, at least for this study.

However, there was no indication from the field that any of the MINDS, Inc failed to operate properly.

CHAPTER 6. CONCLUSIONS

The reasons why three truck deliveries were later than the approximately 1 hour round trip need not be explained here. The point is one of data collection and the patterns produced. It can be assumed that this setting is typical of each such construction site. As such, it can be expected that 3% of all truck load deliveries will exceed the average roundtrip time.

The time on station for dumping is not essential for this study. The time on station for loading is up to the decision makers reading this study and those who work at the asphalt plant.

Data errors were human in nature and occurred at the weigh station. Replacement of humans with automatic recording devices should eliminate this type of error; the RFID technology worked as expected.

A key feature of this study is the requirements shift that occurred once the research team entered the field. The set of initial requirements changed significantly. Many assumptions were violated. This is typical of such projects and should be considered for any next project.

There are two functional areas of research that have to be examined prior to implementing an RFID system for AKDOT. The "two core functional areas of RFID middleware, data management/monitoring (how information gathered from RFID devices is handled) and device management/monitoring (how RFID devices areconfigured and controlled)" (O'Connor, 2004, para. 6).

O'Connor (2004), describes data management/monitoring further as, "data aggregation and integration, or the process of collecting the data from RFID devices and merging it with the company's existing IT infrastructure" (para. 7). Additionally, data management involves, data filtering which is "a set of rules devised by the end users is used to filter out redundant or unneeded information" (para. 7). Following that step is data routing, "which is the process by which the clean data is sent to all of the members of the RFID network" (para. 7).

The data collected for this experiment was not aggregated except as part of the data analysis which demonstrated the time delay aspect of the data collection events. For a continuous use of RFID data collection, the integration of this data within the legacy framework of truck ticket data collection needs to be designed as part of a data management process. The filtering of this experiment data only occurred at the end of the experiment, not during the data collection phase. All raw data collected was analyzed. Only then was it shown that there were errors in the data collection. These errors such as no recording of the event, or a decision my AKDOT management that within the expected time frame of a roundtrip lasting approximately one hour, that any data collected outside that range by at least 3 standard deviations would be suspect of some outside anomaly in the truck delivery routine. This happened two times when the time recorded was five hours compared to the nearly one hour average.

The other aspect not fully explored in this experiment was, device management/monitoring. This is where RFID data collection drivers, "which is the operating software that run the RFID devices and is housed in RFID readers” (O’Connor, 2004, para. 7). It also consists of “control systems diagnostics, alerts and notifications” to the truck drivers and any online monitoring by AKDOT or the vendor or carrier (O’Connor, 2004, para. 7).

While this data management process is part of a requirements needed for a completely integrated RFID solution, there is a cost factor to consider. The cost of the middleware to handle all this data management can range initially from $50,000 to $100,000 (O’Connor, 2004, para. 8).

This experiment was more in line with what happens in manufacturing and retail market experiments, where RFID tags are applied in a slap-and-ship method compared a more integrated method, where the tags are a permanent part of the truck or chassis (O’Connor, 2004, para. 8). Each truck and the paver was equipped with RFID tags only for the timeframe of one construction run, versus all construction projects for the summer 2010 season.

The collection of electronic data using RFID technology proved successful in this closed-loop road construction study. The events were of pickup and delivery of asphalt with roundtrip and time on station for loading being key variables that helped describe the initial intent of this study.

CHAPTER 7. FUTURE RESEARCH

To improve readability of the trucks entering a virtual or fixed gated lane of traffic, the additional use of an optical character recognition (OCR) could be used to read the license plate number of each truck as a backup or redundant system of identification of each truck (Wessel, 2009, para. 4). This OCR added layer of tracking and tracing the truck would only work with the truck having a license plate free of debris, such as mud or ice. Since the construction season is in the summer months in Alaska, this may not pose a problem for the OCR reader. But, as an addition to the tracking and tracing process, this adds a step for the carrier to insure that all license plates are clean during contracted delivery of construction product. Adding the OCR reader process step is used to link “the truck's tag ID number with the container's ID” (Wessel, 2009, para. 5).

Adding the OCR as a process step can be useful to verify the job ticket. Upon the database being automatically updated with the OCR and RFID tag information, that data becomes useful information linking the driver and the load at the specific billable time of delivery. Once both identification steps are taken, the driver could be issued an electronic job ticket via the driver’s cell phone. This additional notification step to the driver still eliminates the need for paper job ticket, but is an added feature to alert the driver that the DOT and the carrier company database has been updated with that job ticket, the driver, the unique truck identifier, and the time of arrival at the dump site.

The process step of sending a notice to the truck driver upon delivery of the load could also be used to not alert the DOT and the carrier, but, if the driver had to respond to the cell, as a text message, confirming the delivery. This would add another layer of redundant confirmation of the time of the load delivery. This added interface by the driver helps insure that the truck and its load have been properly read, but also insure that this event has occurred. The physical act of texting a canned confirmation notice, such as “Confirm arrival,” with a set response of “Yes” or “No” would indicate if any error has happened in the truck identification, but possibly more importantly for billing, is an electronic receipt or electronic signature from the driver that the load has been delivered. Any delay between the driver sending the automated response of “yes” or “no” would indicate some other issue with the driver’s location.

One other feature of notifying the driver is to determine how many trucks are ahead of the driver. The driver could be instructed to text that number upon arrival at the virtual gate. If the driver indicated there were two or 20 trucks ahead, this data could be used later by DOT and by the carrier to address any claims of payment challenge or other legal disputes. If the driver is also given a set of instructions to send a text saying “Dumping now,” the carrier and DOT could have a better indication of any issues with the temperature problems with asphalt loads specifically.

If AKDOT is serious about investing in RFID technology, one other aspect of tracking each truck would be similar to what Wessel (2009) reported. That is, as each truck leaves the construction site area, following the dump of asphalt, that RFID tag, not the OCR, is read again. This could be another virtual gate, but one that is fixed on mobile pedestal as the truck enters the construction exit area. This would be a final read of time on station for this truck. The driver would receive a final update of the total transaction time. Now, the question that has to be discussed is the total paperless process for this application. It may be prudent for the next few years to allow the driver to receive an automated printout at from this mobile pedestal at the final virtual gate stop. The paper ticket would allow the driver to have in their possession a paper copy of the transaction should they be stopped for inspection by the Alaska State Troopers, thus avoiding a prolonged delay and possible fine for the carrier.

There are potential drawbacks in using any technology such as barcodes, RFID and RFID (Hedgepeth, 2007). For the additional use of OCR, Wessel (2009) observed, “OCR system would not always successfully read a truck's license plate, since the vehicles may carry their plates in different positions, such as inside the windshield” (para. 9). This would have to be an area of discussion with the carrier contracted to deliver the asphalt.

The AKDOT needs to develop RFP’s with more flexibility in changing the requirements of their studies. The constant debate over what is termed requirements creep undermines the value of such studies. While these results of this simple study proved a technology point, more thought needs to be put into the initial design of RFP. Suggest that additional, similar RFP’s have a RFI and open discussion period with possible vendors and researchers to determine a more solid set of unchanging requirements.

REFERENCES

Alabama DOT. (2009). *Low visibility warning system*. Retrieved at the University of Alaska Anchorage on November 11, 2009 http://knowledge.fhwa.dot.gov/cops/hcx.nsf/2dcd3639a737386d852568d00082a9c4/ebad659d5dd65a0385256d60005df135/$FILE/bpAlabamaCasePDF.pdf

Alabama DOT. (2008, November 28). Information technology as a critical element of the transportation infrastructure: Critical analysis in modern transportation agencies. *Transportation Research Record: Journal of the Transportation Research Board*, 2064, 19-23.

Alabama DOT. (2007, January 26). Statistics for superpave hot-mix asphalt construction quality control/quality assurance data. *Transportation Research Record: Journal of the Transportation Research Board*, 1813, 151-156.

Alabama DOT. (2006). *Alabama bridge information system.* Retrieved at the University of Alaska Anchorage on November 11, 2009 http://www.dot.alabama.gov/NR/rdonlyres/AB9F8A1C-3901-4CAB-B8A8-CA8ACA664D0A/0/ABIMSUserManual.pdf

Alaska Department of Transportation Memorandum. (2006) . Retrieved at the University of Alaska Anchorage on November 11, 2009 http://dot.alaska.gov/stwdplng/cip_stip/assets/06_08stip/06_08amendments/06_08_amd5approved.pdf

Alaska Department of Transportation. (2006) . *Birchwood airport.* Retrieved at the University of Alaska Anchorage on November 11, 2009 http://www.dot.state.ak.us/stwdav/ALP/Birchwood_ALP.pdf

Alaska Department of Transportation. (2006). *Strategic plan.* Alaska University Transportation Center. July 24.

Alaska Department of Transportation. (2006). *Tuluksak airport haul routes.* Retrieved at the University of Alaska Anchorage on November 11. http://www.dot.alaska.gov/creg/tuluksak/assets/tuluksak_apt_EA_appG23-49.pdf

Almanza, D. L., Hernandez-Gutierrez, A., & Ibarra-Manzano, M. A. (2006). *Design and implementation of a vehicular access control using RFID*. IEEE. MEP 2006. November 7-11.

Alva, S., Tavares, M. P., & Andres, N. P. (2006). *Ride specifications review for the Montana department of transportation.* The State of Montana Department of Transportation (FHWAVMT--6-004/8179). August.

Arrington, C. A. (2009). *An investigation into short range RFID tag for highway asset management*. Virginia Tech and Virginia Department of Transportation (VDOT). CHAMPS 2008. February 6.

Attaran, M. (2009). *Keeping the promise of efficiency*. Industrial Engineer. March, 45-49.

Avoine, G. (2007). Bibliography on security and privacy in RFID systems, *Massachusetts Institute of Technology*, 1-10

Bierwagen, D., Abu-Hawash, A. (2005). *Ultra high performance concrete highway bridge*. Proceeding of the 2005 Mid-Continent Transportation Research Symposium, August. 1-14.

Blanchard, D. (2009). *The five stages of RFID*. Technology & Innovation. January, 50-53.

Borck, J. R. (2008). *Tuning in to RFID*. Infoworld. April 17, 31-36.

Burns, S. E, Ross. W. A. (2008). *Materials tracking technology at the office of materials and research.* Georgia Department of Transportation. (GDOT PROJ NO. 06-08). July.

California Department of Transportation. (2006). *Action plan.* Retrieved at the University of Alaska Anchorage on November 11, 2009
http://www2.dot.ca.gov/hq/transprog/ctcliaison/2006/1106/REAP%20Documents/REAP%205.pdf

Ceylan, H., Gopalakrishnan, K., & Coree, B. (2006). *A strategic plan for implementing the mechanistic-empirical pavement design guide in iowa.* Proceedings of the 85th Annual Meetng of the Transportation Research Board. January 22-26.

Creswell, J. W. (2009). *Research Design*, 3rd Edition. Los Angeles: SAGE.

Curtin, J., Kauffman, R.J., Riggins, F.J., (2007). Making the 'most' out of RFID technology: a research agenda for the study of the adoption, usage and impact of RFID. *Information Technology and Management*, 8, 87-110.

David, M. (2007). *Identify helf: RFID muscles into consumer market.* Technology Report. Electronic Design. February 15, 43-46.

Elango, V.V. (2009). *Safety evaluation of centerline rumble strips.* Thesis Outline. Retrieved at the University of Alaska Anchorage on November 11.
http://www.prism.gatech.edu/~gtg214m/ThesisProposal.pdf

El-Omari, S., Moselhi, O. (2009). Data acquisition from construction sites for tracking purposes. *Engineering Construction and Architectural Management*. November 5. 14: 490-503.

Engels, D.W, Sarma, S. E. (2005). *Standardization requirements within the RFDI class structure framework.* MIT.

Ergen, E., Akinci, B. (2009). *An overview of approaches for utilizing RFID in construction industry*. University of Arkansas. IEEE Xplare.

Fedrowitz, W. J. (2007). *Implementation of RFID technology in VT-VDOT highway maintenance monitoring program (HMMP).* Masters Degree Thesis. Virginia Polytechnic Institute and State University. November 30.

Florida Department of Transportation District One. (2009). *Project development and environment survey*. Retrieved at the University of Alaska Anchorage on November 11. http://www.i-75pde.com/sarasota/5-21-09-Hearing/Public%20Hearing%20Handout.pdf

Florida Department of Transportation. (2009). *Response to the second statement of information needed (SIN) for parkland development of regional impact.* Retrieved at the University of Alaska Anchorage on November 11, 2009 http://www.sfrpc.com/dri/Parkland%20SIN%203/FDOT.pdf

Florida Department of Transportation. (2009). *State road resurfacing project.* Retrieved at the University of Alaska Anchorage on November 11, 2009 http://www.sarasotagov.com/InsideCityGovernment/Content/CAC/PDF/FruitvilleFlyerNewOK.pdf

Friedrich, N. (2007). *RFID innovations deepen market penetration*. News Report. Microwave & RF. January. 33-39.

Fu, Q, Retscher, G. (2009). Active RFID trilateration and location fingerprinting based on RSSI for pedestrian navigation. *The Journal of Navigation*. April. 62:2: 323-340.

Hall, J. P., Robinson, R. & Paulis, M. A. (2005). *Enterprisewide spatial data integration of legacy systems for asset management: the case of the Illinois department of transportation.* Transportation Research Board: Journal of the Transportation Research Board. 1917: 11-17.

Hallmark, S. L., Hawkins, N. R., Fitzsimmons, E., Plazak, D. J., Welch, T. M., & Petersen, E. (2008). *Use of physical devices for traffic calming along major roads through small rural communities in iowa*. Transportation Research Board: Journal of the Transportation Research Board (No. 2078). 100-107.

Hedgepeth, W.O. (2007). *RFID metrics: Decisions making tools for today's supply chains*. Boca Raton, FL: CRC Press.

Hoske, M. T. (2007). *What's your RFID spin?* Control Engineering. February, 44-48.

Hsu, C., Chen, S. (2009). Alleviating reader collision problems in mobile RFID networks. January 14. *Pers Ubiquie Comput,* 13:489-497.

Jirik, T. (2007). *Research opportunities in radio frequency identification transportation applications.* Transportation Research Board. October 17-18.

Jones, A.K., Dontharaju, S., Tung, S., Hawrylak, P.J., Mats, L., Hoare, R., Cain, J., Mickle, M. (2006). Passive active radio frequency identification tags. *International Journal of Radio Frequency Identification Technology and Applications,* 52-73.

Jones, M.A., Wyld, D.C., Totten, J.W., (2005) . The Adoption of RFID in the retail supply chain, *Coastal Business Journal,* 4, 29-42.

Khan, F., Akhtar, N, & Qadeer, M. A. (2009*). RFID enhancement in road traffic analysis by augmenting receiver with telegraph CQ.* Second International Workshop on Knowledge Discover and Data Mining. Moscow, Russia. January 23-25. 9:19: 331-334.

Kieres, C. (2010). *PaveTag Project Quotation*. Minds, Inc. March 22.

Kieres, C. (2010). *University of Alaska -- PaveTag Summary.* Draft report prepared for Dr. Hedgepeth (copy available upon request).

Kilpellainen, P., Heikkila, R., & Parkkila, T. (2007). Automation and wireless communication technologies in road rehabilitation. *24th International Symposium on Automation & Robotics in Construction (ISARC 2007): Construction Automation Group,* 35-40.

Kulseng, L. S. (2009). *Lightweight mutual authentication, owner transfer, and secure search protocols for RFID systems.* Masters Degree Thesis. Iowa State Univeristy.

Lamont, J. (2005). *Government tunes in to RFID.* KMWorld. June, 20-26.

Lee, J. H., McCullouch, B. (2007). *Automating material delivery records*. Indiana Department of Transportation (FHWA/IN/JTRP-2007/26). June.

Lee, W. J., Song, J. H., Kwon, S.W., Chin, S., Choi, C., & Kim, Y. S. (2008). A gate sensor for construction logistics. *25th International Symposium on Automation & Robotics in Construction (ISARC 2007): Construction Automation Group*, 100-105.

Lim, S. H., Koh, C. E. (2009). RFID implementation strategy: perceived risks and organizational fits. *Industry Management & Data Systems*. November 8. 109:1017-1098.

Lindly, J.K., Narci, A. (2006). *Evaluation of rumble stripe markings*, University Transportation Center for Alabama.

Miller, J. (2007). *Criteria for evaluating RFID solutions for records and information*. The Information Management Journal. January/February, 50-55.

Mohd-Yasin, F., The, Y. K. (2006). *Developing designs: for RFID transponders*. Microwave & RF. September, 57-86.

Murray, C. J. (2006). *RFID: Beyond the drive for five*. Design News. April 24. 48-52.

Newnan, D.G, Lavelle, J.P., & Eschenbach, T.G. (2009). *Engineering economic analysis*, 10th Edition. New York: Oxford University Press.

Oregon Department of Transportation. (2008). *Geographic information systems (GIS) strategic plan*. Retrieved at the University of Alaska Anchorage on November 11, 2009 http://library.state.or.us/repository/2009/200906011138131/index.pdf

O'Connor, M.C. (2004). RFID Users Want Clean Data. *RFID Journal*. Nov. 11, 2004.

Pal, A., Triche, M.H., Graettinger, A. (2005). *Enhancements to evacuation procedures emergency*, University Transportation Center for Alabama.

Parker, F., Hossain, S. (2007). *Statistics for superpave hot-mix asphalt construction quality control and quality assurance data*. Transportation Research Record. 1813: 151-156.

Pendleton, T. A., Sussman, J. M. Regional architectures: strengthening the transportation planning process. *Proceedings of the 2006 Multiconference on Electronics and Photonics; Embodied Meetings; 3rd International Conference of Advanced Optoelectronics and Lasers, CAOL, 2006; 3rd International Conference of IEEE*. Transportation Research Record (No. 1679). Paper No. 99-0997. 11/11: 223-225.

Plazak, D. J., Garms, A., Rees, J. (2006). *Access management plan and program for des moines, iowa, metropolitan area.* Transportation Research Record. Journal of the Transportation Research Board (No. 1981). 142-147.

Rawal, A. (2009). RFID: *The next generation auto-id technology*. Microwave Journal. March, 58-76.

Richardson, J., Triche, M., Skelton, S. (2005) . *Development of a Transducer for Measuring Tensile Strains in Concrete Bridge Girders*, University Transportation Center for Alabama.

Rodrigue, J. P., Comtois, C., & Slack, B. (2006). *The geography of transport systems*, 2nd Edition. New York: Routledge.

Ross, W. A., Burns, S. E.,Wu, P. Y. & Jared, D. M. (2009). *Transportation Research Record: Journal of the Transportation Research Board: No. 2098*. Transportation Research Board of the National Academies. Washington, D. C. pp. 3-12. DDI: 10.3141/2098.01

Seah, K. A. (2009). *US Patent 7605688 -- Vehicle location determination system using an RFID system.* US Patent Office.

Singer, P. (2005). *A new approach to low-cost RFID tags*. Technology News. Semiconductor International . Reed Business Information. http://www. Semiconductor.net.

Smith, B. L. (2008). Information technology as a critical element of the transportation infrastructure. Transportation Research Report. *Journal of the Transportation Research Board.* (No. 2064), 19-23.

Song, J., Haas, C. T., & Caldas, C. H. (2006). Tracking the location of materials on construction job sites. *Journal of Construction Engineering and Management*, September, 911-918.

Transportation Research Board. *Research opportunities in radio frequency identification (RFID) transportation application.* 10 – 17/18 – 06. Transportation Research Board of the National Academics.

US Department of Transportation Federal Railroad Administration. (2009).) *Preapplication Raw Data Statistics.* Office of Passenger and Freight Programs (RDV-10US Department of Transportation. (2007).

Wang, L. (2007). *Enhancing construction quality inspection and management using RFID technology*. Automation in Construction. January, 467-479.

Wessel, Rhea. (Aug. 13, 2009). DP World Ramps Up Its Dubai Deployment. *RFID Journal.*

Wyld, D. C. (2005). RFID: *The right frequency for government.* IBM Center: The Business of Government.

Zhou, S., Ling, W., & Peng, Z. (2006). An RFID-based remote monitoring system for enterprise internal production management. *International Journal of Advanced Manufacturing Technology*. 33: 837-844,