ELECTRONIC TOLL AND TRAFFIC MANAGEMENT PROJECT

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Task 31a

Wireless, Solar Powered Tag Reader

Final Report

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The Electronic Toll and Traffic Management (ETTM) project was a $1.1 million effort sponsored by the Federal Highway Administration (FHWA) and the New York State Department of Transportation (NYSDOT). It began in June 2005 with the goal of using wireless technology to enhance the observability of the transportation network to improve management of the system. Another goal of the ETTM project was to develop and test wireless, solar-powered tag readers, and provide real-time travel time information. These new detectors will be available for use in areas where power or communications infrastructure do not exist or for temporary areas where additional monitoring is desired like arterials, work zones or planned special events.
Table of Contents

1 INTRODUCTION ............................................................................................................. 1

2 APPROACH AND METHODOLOGY ............................................................................... 2

2.1 Task 22: Preliminary Design of Experiments for the ETTM Device 2

2.2 Task 23: Create First Prototype E-ZPass Reader 2

2.3 Task 24: Test and Enhance the New Tag Reader 3

2.4 Task 25: Fabricate Five Additional Tag Readers 4

2.5 Task 26: Finalize the Field Experiment Plan 4

2.6 Task 27: Prepare the Experiment 6

2.7 Task 28: Conduct the Experiment 6

2.8 Task 29: Assess the Results 9

2.9 Task 29a: Data Quality Assessment 10

2.10 Task 30: Investigate Data Fusion Methodologies 11

3 FINDINGS AND CONCLUSIONS ............................................................................... 12

3.1 Task 31b: Prepare the Evaluation Report 13

4 REFERENCES ............................................................................................................ 14
1 Introduction

Radio frequency identification (RFID) technology has been proposed as a means of observing traffic as part of an automatic vehicle identification (AVI) system. To date, many of the deployments of the technology have been using fixed installations, typically on freeways. Some examples of these deployments include the TRANSMIT system in New York and New Jersey and the FasTrak™ system in California. This project provided a demonstration of RFID tag reader technology, more specifically E-ZPass toll tag technology, for collecting link travel times where permanent installations were not practical. For example, the technology could be used for traffic management on local arterials, during special events or through work zones.

This Electronic Toll and Traffic Management (ETTM) project was initiated in August 2005 and completed in December 2010. This project was conducted as part of the Advanced Traveler Information System (ATIS) Implementation and Integration project. The project was led by Rensselaer Polytechnic Institute (RPI) with support from Mark IV Industries, Annese and Associates, North Carolina State University (NCSU) and Polytechnic Institute of New York University. The work was funded by the New York State Department of Transportation (NYSDOT) and the Federal Highway Administration (FHWA).

As part of this project the team designed, built and deployed six prototype wireless, solar powered E-ZPass tag readers. Between July 2007 and early January 2008 the tag readers were deployed in the Capital District Intelligent Transportation System (ITS) Testbed in North Greenbush, NY and at a planned special event in Syracuse, NY during the New York State Fair. The North Greenbush, NY deployment served as a system test on an arterial while the NYS Fair deployment served as a real-world deployment of this technology at a planned special event and through a work zone.

As stated in the work scope, the goals were to:

- Develop a preliminary field experiment plan;
- Create a prototype of the wireless, solar powered tag reader;
- Test and enhance the prototype tag reader;
- Build five additional prototype tag readers;
- Finalize the field experiment plan;
- Prepare the experiment;
- Conduct the experiment;
- Perform a data quality assessment for the two main components of the project;
- Assess the results collected during the data collection;
- Create methodology for fusing various types of transportation data.
The following sections of this report summarize the findings from the various task reports that were conducted as part of this project; more detailed information can be found in the specific task report. The report is organized as follows. Section 2 presents the project approach and methodology including summaries of Tasks 22 through 30 and Section 3 provides findings and conclusions; this Task 31a Report and supplement Task 31b Evaluation Report comprise the Final Report for the Electronic Toll and Traffic Management project.

2 Approach and Methodology
The ETTM project began with Task 22 and was concluded with a final report as part of Task 31. Tasks 22 through 25 focused on the design, construction and initial testing of the prototype unit. Tasks 26 through 29 dealt with the field testing of the devices. Task 30 focused on creating a data fusion methodology for various types of traffic data; a case study from the deployment at the NYS Fair is presented. A summary of each task is provided below in chronological order.

2.1 Task 22: Preliminary Design of Experiments for the ETTM Device
The objective of the Task 22 report was to present a preliminary field experiment design for the wireless, solar powered tag reader project (1). This report presented a preliminary field experiment plan based on the data obtained from the ATIS project. As part of this plan, locations were identified where possible tag readers could be deployed for various experiments. During this phase of the project it was expected that a number of the pocket PC devices that were deployed during the ATIS project would be also used as in-vehicle data sources to provide data that can be compared to that collected by the tag readers. However, due to contractual delays on the project it was not feasible to do this.

This task was completed in August 2005.

2.2 Task 23: Create First Prototype E-ZPass Reader
Task 23 was comprised of developing the first prototype wireless, solar powered E-ZPass tag reader (2). During this task, RPI, Mark IV Industries and NCSU worked closely to ensure that the first prototype would need few modifications and would function as intended. The first prototype unit was comprised of an mGate tag reader from Mark IV, a solar panel, a weatherproof cabinet, a laptop computer, two 100ah batteries and the necessary circuitry. These components were installed on a small trailer with an extendable mast. On the mast an antenna and pan/tilt motor was installed. The purpose of the pan/tilt motor was to easily adjust the antenna when deployed. Some of the concerns that were addressed during the prototype included the following:
• Power consumption of the device,
• Power components of the system,
• Communication devices,
• Method of field installation, and
• Data processing including which data items to transmit and how to securely encrypt the data.

The prototype was capable of working in a typical field deployment situation under favorable weather conditions; it was not a field-hardened device.

Although this task was delayed due to contracting issues RPI and Mark IV began exploring various options in March 2006. In July 2006 the components of the first prototype were delivered to RPI from Mark IV. During this time RPI was able to secure a trailer with a mast. In July 2006 the trailer was modified to accommodate the components for this project. Once the prototype was built the team spent several weeks doing controlled testing in parking lots. On August 31, 2006 a workshop was held with the project partners. The purpose of this workshop was to demonstrate the first prototype and make sure everyone agreed to the design. For the first prototype the device that was used to process the tag reads was a standard laptop computer. The team noted that they were working with Annese and Associates to change the platform to a pocket PC. The pocket PC would encrypt the tag data and upload it to a central server.

2.3 Task 24: Test and Enhance the New Tag Reader

The Task 24 report served as the product development report on the creation of the wireless solar powered tag readers. This report documented the development process, its associated lessons learned, and the enhancements made to the reader during initial testing (3).

The report discussed the hardware and software components found in the prototype design as well as alternatives that were considered. For the original prototype design the following sections were covered:

- Solar mGate components, including,
  - mGate reader,
  - Power components, and
  - Enclosure;
- Field mounting options, including,
  - Pole mounted options, and
  - Trailer mounted options;
• Hardware & software issues.

The Task 24 report is intended for general distribution. However, some information relevant to the device’s design is the proprietary information of Mark IV Industries and is not releasable to the general public. All proprietary information is contained in a separate report with distribution approval required by NYS DOT and Mark IV Industries.

When the testing and reader enhancements were completed, a meeting with the NYSDOT project manager was held. The purpose of this meeting was to get consent to fabricate the five additional tag readers (Task 25).

This task began in September 2006 and enhancements to the prototype were completed by December 2006. The report was submitted in August 2007. The reason for this delay was the development of the data encryption software for the pocket PC (PPC) platform. This software was under development from October 2006 until the Spring of 2007.

2.4 Task 25: Fabricate Five Additional Tag Readers

The purpose of this task was to build five additional wireless, solar powered tag readers that were identical to the enhanced tag reader delivered as part of Task 24 (4). Since the changes resulting from Task 23 were minimal the team decided to build the five additional tag readers simultaneously with the enhancements to the first tag reader. On January 2, 2007 the NYSDOT project manager met with the RPI project manager to see the five completed tag readers. The NYSDOT project manager was satisfied with the devices and deemed the task complete.

2.5 Task 26: Finalize the Field Experiment Plan

The main objective of the Task 26 report was to finalize the field experiment plan that was set forth in Task 22 (5). Since the prototype reader has been built and tested, the Task 22 field experiment plan needed to be updated based on the actual operating characteristics of the tag reader.

On August 31, 2006 a meeting was held at the RPI Technology Park, to discuss possible deployment options for the tag readers. This meeting was held on the same day as the Task 23 workshop that presented the first working prototype device. The purpose of the workshop was to engage the stakeholders in discussion on where to deploy the tag readers in the ITS Testbed along Route 4.
In May 2007 discussions and field visits were made to the proposed locations. Based on these discussions and visits, the sites were modified so the trailer would be deployed in a location that allowed for reliable data collection while also ensuring safety alongside the roadway. The map shown in Figure 3 represents the locations the team agreed to deploy five of the tag readers. The north-south road to the right of the picture is Route 4 and the north-south road to the left is I-787. At each one of the red circles the team planned on deploying one reader that would capture one lane of traffic in a side-fire application. For vehicles equipped with E-ZPass the through movements on Route 4 north and southbound can be captured as well as the turning movements into the RPI Tech Park (location #1). It was decided that the sixth reader would not be deployed initially and served as a backup if needed.

![Map of proposed deployment locations](image)

**Figure 3  Proposed deployment locations**

The travel times could be monitored for the vehicles traveling between the following pairs of readers:
- Reader 1 to Reader 5 (Jordan Road to Route 4 northbound)
- Reader 1 to Reader 3 (Jordan Road to Route 4 southbound)
- Reader 2 to Reader 3 (Route 4 southbound)
- Reader 2 to Reader 1 (Route 4 southbound to Jordan Road)
- Reader 4 to Reader 5 (Route 4 northbound)
- Reader 4 to Reader 1 (Route 4 northbound to Jordan Road)
Due to safety considerations the trailer mounted deployment option was not feasible at three of the locations (numbers 3, 4 and 5 above). At these locations a sign mounted antenna was constructed.

2.6 Task 27: Prepare the Experiment

The objective of this report was to explain the process whereby the wireless solar powered tag reader field experiment was prepared and the lessons learned during the process. The Task 26 report outlined the anticipated deployment plan; this report describes the actual deployment of the readers. This report includes information on both the NYS Route 4 deployments in North Greenbush, NY and the deployments that were made at the NYS Fair in Syracuse, NY (6).

In June and July of 2007 the wireless solar powered E-ZPass tag readers were deployed along NYS Route 4 and Jordan Road in North Greenbush, NY. These locations were selected as part of the Task 26 effort. In mid August 2007 the readers were then transported and deployed near Syracuse, NY during the NYS Fair. Upon completion of data collection at the NYS Fair, the six readers were again redeployed in North Greenbush, NY until January 2008. The task report discusses in detail each of these deployments.

During the installations the team continued to learn a great deal about the devices and how they should be placed for optimal performance. There were a number of issues that had to be resolved dealing with the site deployments of the readers. Besides choosing locations that were ideal in terms of measuring travel times, the team also had to take into account safety issues such as the devices proximity to the road and how to obtain permission to park the devices on private property.

2.7 Task 28: Conduct the Experiment

The Task 28 report focused on conducting the experiment. This task report was done as part of a combined Task 28 and 29 report because of the overlap between the two tasks (7). As part of this task the movement of tagged equipped vehicles through the testbed area was monitored and the performance of the wireless solar powered tag readers was documented. These deployments served mainly as a system evaluation, whereas the testing in late August 2007 at the NYS Fair served as a deployment at a real work zone and special event for monitoring travel times. With the Route 4 testing the team was fortunate enough to have the readers deployed during all types of weather conditions such as hot humid days, severe rain and wind as well as snow and ice.

Traditionally, antennas for tag readers are installed directly over the travel lane (overhead). As part of this project, the reader’s antenna was installed at the side of the road, in a side-fire configuration. In most of the installations the reader was deployed on the shoulder of the road,
resulting in the traffic from only one lane being captured. In one case it was possible to deploy the reader on a center median island and capture traffic in both directions (Photos of these sites can be seen in (6)).

It is important to note that this device being tested was a prototype and was not field hardened. Most all of the components that comprise the system were found to be durable during the field evaluation. There were a few failures due to condensation damage to the coaxial components but these were relatively rare and with the proper weatherproofing were eliminated. The device also performed very well in icy and snowy conditions.

The most problematic component of the system was the communication device. The Pocket PC (PPC) that was used claimed to be one of the more advanced devices on the market at the time. However, the PPC produced most of the failures while the system was deployed. The team was fortunate to have the ability to view the web application and see the last tag transaction for each of the readers. If there were no recent tag reads then the team could go to the field and reset the necessary devices. The primary failures with the PPC included Bluetooth instability between the PPC and Bluetooth serial adapter, insufficient operating memory and in a few cases, random failures with the custom encryption software.

Since the PPC did not have any ports that would allow for a hard wired connection to the mGate reader it was necessary to use an AIRCable Serial Bluetooth adapter. This device was unique in that the RS232 cable from the mGate reader was plugged into it and the device transmitted the output data to the PPC via Bluetooth. The communications between the PPC, Bluetooth device and mGate reader would sometimes terminate at random, with no predictability as to when this might occur. In some cases the devices would stay connected for over 200 hours, while in other cases they would disassociate after a few tag transactions or in some cases not connect at all. Since there was no way to log each type of failure only an estimate could be made. It is estimated that the Bluetooth failures were at least half of the total failures of the device.

When the system was originally designed it was not built to power any type of communication device. This was because the original plan was to test the tag reader and its components and
see how well it would function when powered by a solar panel. The team then decided to push the envelope and see how it would function in a 24/7 environment while providing power to the PPC and Bluetooth adapter. The system was able to power all the components for much of the study even during cloudy days. The period from late November until mid January in the Capital District Region of New York State proved to be the most problematic for the solar components. This was because it was the time leading to and following the shortest day of the year. Moreover, many of the days had no sunshine. Because of the weather the solar panel could not provide enough power to run the device and charge the batteries. It should be noted once again that the system was not designed to power the PPC and Bluetooth device, just the mGate reader. This extra power consumption was the main reason for the power failures.

On average the devices would operate for 38 hours before shutting down, again in most cases this was due to the PPC reliability.

![Figure 5 Average number of failures per device per month](image)

The bar chart in Figure 5 shows how the average number of failures per month relates to the various components within the system. It is obvious that the PPC related failures were most prevalent, comprising approximately 50% of the failures each month. The chart also indicates that the most failures occurred in July 2007 when the initial testing was taking place. This was because the team was still learning how to optimally deploy the devices. Additionally, the chart indicates that in December and January there were a large number of solar panel and battery failures; these failures were related to the lack of sunshine to charge the system. The original intent of the project was to test the mGate reader during favorable weather conditions (not the
communication components). When the team had the opportunity to continue testing through the winter months it was anticipated that the solar components would not perform as well as they did in the summer and fall. If it were possible to improve the reliability of the PPC and associated software the number of failures per device would likely be less than five per month.

### 2.8 Task 29: Assess the Results

The Task 29 report focused on assessing the results from the experiment. This task report was done as part of a combined Task 28 and 29 report because of the overlap between the two tasks (7). Few projects have been able to study arterial travel times using AVI equipment; tag readers are rarely deployed this way. This project not only provided an opportunity to study the AVI system performance, but it allowed these findings to be compared with an earlier project at the same location where an AVL experiment was performed. The task report provides a detailed travel time analysis for both the North Greenbush and Syracuse, NY deployments.

In studying the data it was found that estimating reader to reader travel times for arterials is not as easy as for freeways. On arterials people may pass one reader then stop at an intermediate point (i.e. home, work, store, etc) before continuing on past another reader. On freeways, the stopping opportunities do not exist, so the travel times are more uniform unless incidents occur; so analysis and prediction/estimation is relatively straightforward; but not so for arterials.

Incident detection and characterization will also be more difficult with AVI systems. Since with AVI systems the whole trajectory will not be known, it will be difficult to distinguish between vehicles that are delayed due to incidents and those that have simply made roadside stops. It will also be difficult to tell exactly where the incident has occurred (if one has) because the only information available will be travel times between AVI readers. In contrast, with an AVL system, it will be easy to spot vehicles that have made a roadside stop and distinguish them from ones involved in or affected by incidents. It will also be easier to see where the incident has occurred because it will be possible to see the AVL vehicles that have been stopped by the incident.

Additionally, the trends in the percentiles for the reader to reader travel time density functions suggest the following:

- The 10th percentile values are likely to be very consistent as will the 50th percentile values; but the 95th percentile values will vary dramatically;
- The mean will vary widely since it is affected by, and is very sensitive to, the long travel times;
- Reader to reader performance metrics predicated on ratios to the mean will be difficult to use;
• It will be better to use metrics predicated on the 50th percentile or ratios to the free flow travel times, or travel times deduced from the speed limits; such as the ratio of the 95th percentile travel time to the free flow travel time.

Not all of the movements will have the same trends and relationships. Some reader to reader pairs will show very stable values, as with right turns where the impacts of signal timing or congestion is likely to be low.

It may be that the 95th percentile will not be the best metric to use as an indicator of travel time reliability. A lower percentile, like the 10th or 50th, might be better. All of the percentiles are affected when there are incidents; but the lower percentiles seem to be affected only when there are incidents, whereas the 95th percentile has a lot of volatility, caused by other factors.

While the 95th percentile value does vary, in many cases, the overall trends can still be used to provide guidance to travelers about what travel times to expect. Based on the plots of the travel times, one can make statements like: half of the travelers for this reader to reader pair need X minutes, so allowing that much time will be fine if you are someone who drives faster than about half of the population; but if you want to be sure you are not late, you should allow Y minutes. You are likely to be quite early, but you will not be late.

2.9 **Task 29a: Data Quality Assessment**

Following lessons learned in the Advanced Traveler Information (ATIS) project, the team added Task 29a to the project. This task dealt with the process of cleaning and validating the data collected during the ETTM project. The data that was assessed came from the six wireless solar powered E-ZPass tag readers when they were deployed as part of the testing identified in the previous sections of this report (8).

Before proceeding with any data analysis it was necessary to study the data and ensure the records were ‘clean’ and valid. For this project the utilization of the data is to estimate both the travel times between pairs of readers and the efficiency of the readers. The data cleaning was performed for both the North Greenbush and Syracuse deployments.

In this task report the data structure was identified. During the cleaning process redundant and irrelevant fields were removed. Then the data was checked for formatting errors, none were found. Test tag reads, duplicate tag reads and multiple records were then removed.

After eliminating errors in the data, 99.1% and 98.7% of the records for North Greenbush and Syracuse respectively were found to be valid and reliable data points.
2.10 Task 30: Investigate Data Fusion Methodologies

The objective of the research in Task 30 was to propose a data fusion methodology that provides more accurate and reliable link travel times to support the implementation of real-time transportation management strategies (9). This report focused on transportation management for traffic congestion of passenger vehicles on road infrastructure, which included highways, arterials and local roads. The indicator of performance used was link travel times, where a link is defined as the length between consecutive ramps on a highway, and the length between consecutive signalized or major intersections on an arterial or local road. The technologies used include fixed, mobile and portable sensors.

Sample data were collected from a middle-size urban metropolitan network; the Syracuse, NY area during the NYS Fair. Data from passenger vehicles were collected from five different types of sensors: inductive loops, pneumatic tubes, passive array acoustics, RFID tag readers and probe vehicles with GPS technology. Traffic data was collected under normal conditions, during a special event, and through a work zone.

The Task 30 report provides a description of the different types of sensors, an explanation of the characteristics of each of the traffic variables, the methodology developed to perform the Multi-Sensor Data Fusion and the methodology developed for the estimation and prediction of link travel times.

In addition to offering a data fusion methodology this report made the following conclusions:

- Data obtained from different sensors not only provide different measures of traffic, but differ on their reliability, accuracy, completeness, penetration, recording time intervals and spatial configuration. Despite these differences they all provide data on the traffic conditions, each of them with their own strengths and weaknesses. These data sources used in concert are complementary and provide a more complete picture of the network traffic conditions than any individual sensor.

- Traffic variables describe the characteristics of traffic flow. Traffic variables have different characteristics depending on the type of road, time of day, and day of the week. Besides the characteristics of each type of road such as capacity, speed limits, and presence of signals and intersections, other factors influence the behavior of the traffic flow. Commuting times; weather conditions such as rain, fog, and snow; construction zones; special events; and incidents are some of the factors that have an effect on the traffic flow characteristics.

- No data collected from a single source can be assumed to be ground truth. Travel times from volume and speed have less variability and register measurements for every time period, but sometimes fail to detect peaks and tend to be underestimates. Travel times
from RFID tag readers have several missing values and have greater variability, and tend to overestimate the measurements.

- The data fusion methodology showed flexibility to work with data sources of different reliability and with different variability. The proposed fusion technique demonstrates its complexity to represent successful changes in traffic patterns; and recognizing incidents and estimating their magnitude reasonably well.

This task began shortly after the commencement of the project in 2005 and finished in December of 2010.

3 Findings and Conclusions

This project which involved designing, building and testing prototype wireless, solar powered E-ZPass tag readers was a success. This type of device is of value to state agencies that are in need of monitoring travel times at locations where traditional practices are not feasible. This technology will provide a great data source for arterials, work zones and planned special events. However, it is important to note that in order for this technology to work it is necessary to have a high percentage of E-ZPass toll tag transponders deployed in the traffic stream. Currently, there are fourteen states that use E-ZPass technology, they can be seen in Figure 6.

In conclusion, these wireless, solar powered tag readers do work. They function well under a wide variety of environmental conditions and capture passing tag equipped vehicles. A field hardened device would make the system more reliable, and a larger solar panel would ensure that the system continues to function on winter days when there is little sun and cloud cover; but those are design improvement details. The technology is sound, functional, and useful.

Moreover, the data from the detectors is very useful. The data can estimate travel times, identify incidents, monitor travel time reliability, etc. The data are not as valuable as that provided by AVL equipped vehicles, where the entire vehicle trajectories can be observed. However, the AVI systems are better than point detectors where the status of the network can only be observed at the instrumented locations, and travel times are difficult if not impossible to estimate.
3.1 **Task 31b: Prepare the Evaluation Report**

This task was conducted by researchers at Polytechnic Institute of New York University (10). The evaluation team monitored progress with the project since it began in August 2005. Following the data collection and the data analysis for the project report was drafted to evaluate the processes used during the project. The report evaluates the project as a whole and discusses issues such as the contracting process, the team partnerships, project management and the business case for a wireless, solar powered tag reader.
4 References


