Electronic Toll & Traffic Management Project

Tasks 28 and 29:

Conduct the Experiment

and

Assess the Results

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1 Introduction

RFID technology has been proposed as a way to observe traffic as part of an AVI system. To date, many of the deployments of the technology have been using fixed installations, typically on freeways. Some examples of this are the TRANSMIT system in New York and New Jersey and the FasTrak™ system in California. This report serves as the task report for both Tasks 28 and 29 of the Electronic Toll and Traffic Management (ETTM) project. Task 28 was to Conduct the Experiment and Task 29 was to Assess the Results, since there is overlap between the two the task reports have been merged into one document. This project provided a demonstration of RFID tag reader 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 or during special events or work zones.

This report describes the field demonstrations for the RFID tag reading technology designed to be deployable anywhere to collect link travel times for traffic management. The work was part of the ETTM project conducted by Rensselaer Polytechnic Institute (RPI) under the sponsorship of the New York State Department of Transportation (NYSDOT) and the Federal Highway Administration (FHWA).

Multiple wireless solar powered E-ZPass tag readers were deployed and tested at two locations in upstate New York. The readers were deployed from July 2007 until early January 2008 in both the Capital District ITS Testbed located in North, Greenbush, NY and at the New York State Fair in Syracuse, NY. Data were collected from the US Route 4 corridor, a two-lane arterial in North Greenbush, NY from July 2007 until January 2008. In close proximity to the test sites there was both a community college and a technology park accessed by Route 4.

The report is organized as follows. Section 2 discusses the performance of the wireless, solar powered tag reader; Section 3 describes the data collection process for the project. Section 4 focuses on the data structure and data cleaning; Section 5 provides an analysis of the travel time data collected for both North Greenbush, NY and at the New York State Fair in Syracuse. Lastly, Section 6 offers some concluding remarks.

2 Device Performance

This section of the report focuses on the results from conducting the experiment (Task 28). 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 is documented.

Six of the wireless, solar powered mGate™ tag reading devices were deployed as shown in Figure 1 along US Route 4 in North Greenbush, New York in July and August 2007 and again from October 2007 until January 2008.
These deployments served mainly as a system evaluation, whereas the testing in late August 2007 at the New York State 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 the Task 27 Report).

Figure 1 Deployment Locations (Rensselaer Testbed)
The antenna deployments along US Route 4 were both trailer mounted and sign mounted. Once the optimal antenna height and angle was achieved in the field the system performed quite well for both types of deployments. The optimal height and angle of the antenna were different for each spot, but general guidelines were used to initially setup the devices. Then, based on the performance of the device, the antenna was adjusted until the most favorable results were achieved. Manual field counts were taken often at each of the readers to check the tag read reliability of the device. When the device was on it was found that in most of the cases for the trailer mounted antenna the reliability was between 90 – 95% capture of the tags in the detection zone. The sign mounted antenna also performed with similar results. The most limiting factor had to do with the antenna’s proximity to the roadway and the number of lanes being captured. For example, at location “5” the sign mounted antenna only captured approximately 55 – 65% of the tag equipped vehicles passing by. The cause for this was not faulty equipment but rather a flared travel lane where vehicles normally drove further away from the shoulder of the road; this location can be seen in Figure 2. The team also believes that a fair number of the tags that were not read by the devices were in unusual situations such as improper tag placement within the vehicle.

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. Besides holding true for rain it was also true for ice and snow.

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. It is unfortunate but there was no way to log the reasons for failure on the device; in many of the cases the PPC would just shut down. 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 PPC vendor was aware of these problems and during the course of the seven month test four ROM updates were released to try and fix the problems. One of the updates was quickly recalled and the vendor told the users to reinstall an older version of the software. 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.

Figure 3 shows the frequency of the failures by month for all six of the tag readers. The x-axis is the consecutive hours the device remained operational without intervention. The most frequent length of time the devices would stay operational was between eight and ten hours.

![Figure 3](image)

**Figure 3 Frequency for length of time readers were on by month**

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 from the shortest day of the year. Moreover, many of the days had no sunshine. Many of these failures accounted for the high frequency of failures after eight to ten hours as shown in Figure 3. This is because often times during that time period a team member would reset the device in the morning as the sun would rise and the device would function until the sun would set later that day. 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. It was found that if more battery storage were available this problem would likely be resolved. October was the month when the readers remained operational for 30 to over 200 consecutive hours. The team believes that this was due to somewhat longer days and improved PPC performance due to a ROM update performed in late September.

On average the devices would operate for 38 hours before shutting down, again in most cases this was due to the PPC reliability. In some cases the PPC would only function for a few hours while in other cases it would function in excess of 200 hours. A device that is more stable and consumes less power is needed to make the system more reliable. It should be noted that some small scale experiments were performed during the summer of 2008 to test a ROM update for the PPC. Although the testing was not as rigorous as the earlier field testing the results showed that the PPC was more stable when connected to the Bluetooth adapter and the connection times were much more reliable.

![Figure 4 Average number of failures per device per month](image-url)
The bar chart in Figure 4 shows how the average number of failures per month relates to the various components within the system. This data is only available for the testing completed along US Route 4 in North Greenbush, NY. 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 as can be seen in Figure 5. 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.

During the deployment at the NYS Fair in 2007 the system had to be operational between the hours of 9:00 AM and 11:00 PM at a minimum. These were the hours the Fair was open and real-time travel time information was critical. It was found that during that time period the six devices were operational 82% of the time on average. One reader was operational only 68% of the time, while three of the readers were operational 87 to 92% of the time. Similar to the US Route 4 deployments it was found that most of the failures were related to the performance of the PPC and/or the Bluetooth device.

3 Data Collection

Tag data were collected in three instances. The first was along US Route 4 in North Greenbush, NY. Route 4 is a two lane arterial serving a community college and technology park. The second and third were at the New York State Fair during 2007 and 2008.

A new record was created every time a vehicle with an E-ZPass tag passed by one of the six tag readers. It was found that the percentage of vehicles with E-ZPass tags typically ranged between 22.5% and 30%. (At the NYS Fair, the percentage was 25%) In principle, this should reflect the tag penetration rate. It probably does, but the percentage is lower than penetration rates reported elsewhere in the state. According to a 2006 survey by the International Bridge,
Tunnel and Turnpike Association, New York State Thruway toll facilities have an average tag penetration rate of 59% and as much as 83% during peak hours (1).

In addition to the encrypted tag ID, reader ID and time stamp, reader diagnostic data was collected. This included the battery health of the PPC and vehicle class as indicated on the tag. These data were sent in real-time to a central server where travel time information was processed and sent to a private, secure application accessed by the World Wide Web. The application had the ability to show a user-defined period of time and show average travel times and speeds between any two reader locations. The report displays pairs of readers that have seen identical tags, with the starting point on the left and the end point on the right. Each reader displays its most recent read, current battery life and the number of tags scanned over the reporting period. In addition, each pair of detectors report the distance between them, the average travel time, the average vehicle speed, and the number of matched tags that were included in the analysis of those two points.

The travel time and speed between a pair of detectors is averaged, and thresholds are defined for each pair of points that represent maximum travel time for which a pair of detectors qualifies. Times that exceed that threshold were not included in the analysis but were logged in the master database. A sample set of the travel times posted to the web can be seen in Figure 6. The figure shows two sets of travel times. The first one is between devices ETTM_6 and ETTM_1 which is the southbound movement on US Route 4 to the Rensselaer Tech Park. The second is between ETTM_6 and ETTM_3 which is the southbound through movement on US Route 4.

![Sample travel time data displayed on web](image.png)
4 Data Structure and Data Cleaning

Two phases were involved in the data cleaning. The first was to drop records that were part of the device testing activity or were duplicates of other records. The second was to ensure that the remaining data records were clean and complete. Errors and inconsistencies in the data were found to arise for many different reasons; the wrong format, missing data, misspellings, redundancy, and contradictory values, etc. A detailed data analysis was used to determine which errors and inconsistencies were most prevalent. Based on the results of the cleaning, the team found that nearly 99% of all records collected by one of the wireless solar powered E-ZPass tag readers were justifiable tag reads and could be used as part of the travel time analysis. Task 29a contains additional details on the findings from the data cleaning process (2).

The fields that were retained in the master database after the data cleaning process were the following:

- **TagID**: Uniquely identifies a vehicle.
- **LocationCode**: Uniquely identifies the tag reader.
- **DateRecorded**: For computing travel times.
- **TimeRecorded**: For computing travel times.
- **Channel**: Identifies travel direction of the vehicle for tag readers equipped with more than one antenna, where each antenna faces a different traffic direction.
- **BatteryPct**: Checks health of the pocket PC battery.
- **VehicleClass**: Used to compute travel times for specific classes of vehicles
- **MountingLocation**: Used to check the tag read reliability of the various mounting locations.

5 Travel Time Analyses

In addition to functionality testing described above, there was an interest was in determining whether the tag data would provide a sense of the travel times in the deployment areas. This section focuses on the results of those analyses (Task 29). Very few previous 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.

5.1 North Greenbush Analyses

This discussion focuses on the data collected in North Greenbush along US Route 4. Figure 1 presented earlier identifies the locations where the tag readers were deployed. Figure 7 shows
a similar but different picture of the same information that shows how the readers relate to one another.

The first step in the analysis was to create unique detector labels for the tag readers at the RPI Technology Park (tech park) entrance. Instead of using a reader and channel designation (since technically there was just one reader and two antennas), “detector #1” was redefined as being the inbound “reader” and a new, virtual “detector #7” was created to serve as the outbound reader, as shown in Figure 7.

Defining the reader-to-reader (R2R) network was next. This network was superimposed on the real one to create virtual links between the readers. These R2R links are the ones on which the trip times were assessed. Based on Figure 7, the R2R links in this virtual network were:

- 6-3: SB trips on Route 4 (2.1 miles)
- 6-1: SB trips into the tech park (1.1 miles)
- 7-3: SB trips out of the tech park (1.1 miles)
- 2-5: NB trips on Route 4 (2.2 miles)
- 2-1: NB trips into the tech park (1.1 miles)
- 7-5: NB trips out of the tech park (1.3 miles)

There were also some R2R links for what might seem to be counter-intuitive trips:

- 5-6: trips “into Troy” or more generally to the north, where the reader 5 is passed as the vehicle leaves the study area and reader 6 is passed when it returns.
- 1-7: trips into the tech park, say during the workday, where reader 1 is passed as the vehicle enters and reader 7 is passed as it leaves.
- 3-2: trips “to Albany” or more generally to the south, where reader 3 is passed as the vehicle leaves the study area going south and reader 2 is passed as it returns.

Sorting the records was the next step. They were first separated into individual datasets by day and then sorted by vehicle ID and timestamp.
Creating the R2R trip time records followed. With the raw detector reads sorted in order by vehicle ID and timestamp, new pairwise records were created where each record indicated: 1) the vehicle ID, 2) the “O” tag reader, 3) the “O” timestamp – date and time, 4) the “D” tag reader, 5) the “D” timestamp – date and time, and 6) the O-to-D R2R trip time.

As a short digression, we use the word trip time here to describe the R2R times because the vehicles might not have gone directly from the “O” tag reader to the “D” tag reader. This is an arterial network and the vehicles can go “anywhere”. The driver might have stopped somewhere along the path from the “O” to the “D” tag reader; or gone elsewhere else, not observable by the six tag readers, between the time when the “O” tag read occurred and the “D” tag read took place. Hence, the true R2R travel times are a subset of the R2R trip times, most likely being among the shortest R2R trip times observed.

Analysis then followed. The most interesting finding was that the maximum R2R link trip times tended to be very long early in the day, upwards of 10 hours. Moreover, they became shorter as the day progressed. Figure 8 shows all of the R2R travel times recorded on Thursday, July 17, 2007 for readers 6 and 3.

The time of the O tag read is plotted on the x axis and the time until the D tag read is plotted on the y axis. The units on the x axis are in days (1.0 = one day or 24 hours) and the y axis is in seconds (36,000 seconds = 10 hours). As the figure shows, at least one of the R2R observations shortly after midnight had an OD trip time of 10 hours. This is likely to have been for someone who arrived home at about 1:00AM (0.08 days) and then left home at about 11:00AM, 10 hours (37,000 seconds) later. Until about 5:00AM (0.2 days) very few R2R trip times were observed, and then the observation rate increases. At first the R2R trip times are very short, probably for people going to work, and then some become much longer, up to 30,000 seconds, probably reflecting R2R times for people coming to work at places along Route 4. The people arrive about 7:00AM (at 0.3 days) and leave about 4:00PM, about 30,000 seconds later (9 hours). The longest R2R trip times get shorter as the day progresses until at about 4:00PM (0.7 days) they all are relatively short.

A major implication of these trends is that estimating R2R travel times for arterial networks will not be as easy as one might hope. It is strikingly apparent that these R2R trip times are very different from those observed for freeways. On freeways, stopping opportunities are far less common, so the trip times are predominantly short unless incidents occur; and the analysis, prediction, and estimation of travel times is more straightforward.
Figure 9 shows that the descending pattern in trip times seems to occur every day. Plotted are the 6-3 R2R times for all 16 Thursdays in the experiment. The maximum R2R time varies slightly, but the descending pattern is always present.

The repetitive pattern leads to an observation that AVL systems will provide better information about R2R travel times than AVI systems. With AVL systems, it will be possible to filter out the
extended/interrupted trips. Although AVL data is more desirable AVI data is more readily available at the present time.

Incident detection and characterization will also be easier with AVL systems. Since the whole trajectory will be known, it will be easier to distinguish between vehicles that are delayed due to the incident and those that have made a stop. It will also be easier to tell where the incident has occurred (if one has) because the location of the vehicles will be known. The whole trajectory can be seen, so it is easier to distinguish vehicles that have made a stop from ones involved in an incident. It is also easier to see where the incident has occurred because the stopped AVL vehicles can be identified.

Additional insight comes from looking at the cumulative Histogram (CHs) for the R2R trip times. Figure 10 shows the CH for times from 6 to 3. The x axis shows the trip time intensity (travel time per mile) observed and the y axis shows the total number of R2R times that were that long or shorter. The figure shows the 7700 values up to 1200 seconds out of the 8377 observed. It is possible to see that the 10th percentile is about 80 seconds (over 1 minute, 1000 observations) and the 80th percentile is about 110 seconds (about 2 minutes, 6500 observations). This means the average R2R time must be about 130 seconds (2.2 minutes); Identifying the upper value is
difficult because the density function has a very long tail, up to 23,000 seconds (6.2 hours).

Traffic engineers hope to use AVI data to improve the quality of information about travel times and travel time reliability provided to the public. The AVI data are clearly useful, but the question is, what quality of travel time information can be developed? In the case of arterials, what data should be used? The results above make it clear this is not an easy challenge.

Important insights come from looking at the trends in the percentiles of the density function as increasingly more data points are included. Figure 11 shows the trends in the 10th, 50th, and 95th percentiles for link 6-3 as more and more of the ordered (shortest to longest) observations are included. Several observations are clear:

- The 10th percentile value is very consistent, as will the 50th percentile values;
- The mean increases steadily, reflecting the fact that the mean is affected by, and very sensitive to, the increasing number of long travel times included as the number of observations grows;
- The 95th percentile value increases dramatically with the number of observations included.

![Percentile TT Intensities for O-D pair 6-3, All Thursdays](image)

Figure 11 Travel Time Intensities across the Day
The trends for the movements are not all the same, as should be expected. As Figure 12 shows, link 6-1 has very consistent values for all the percentiles. This consistency should be expected, however; 6-1 is the link for the right turn coming out of the tech park heading southbound.

![Percentile TT Intensities for O-D pair 6-1, All Thursdays](image)

It may be that the 95th percentile for these individual arterial trip times is not the best metric to use as an indicator of R2R travel time reliability. The analyses below help elucidate the possibilities. The individual days of the week will be examined to see if there were trends in the percentiles from one week to the next.

Figure 13 shows the trends in the 10th, 50th, and 95th percentiles as well as the mean for reader pairs 6-3, 6-1, and 7-3 for the 13 Thursdays for which data were available in the observation timeframe. (Remember that 6-1 is the southbound right into the tech park and 7-3 is the southbound right out of the tech park.) What stands out immediately is the dramatically higher percentile values on the 12th Thursday. Before consulting historical records, it is clear that there must have been an incident that day; and the impacts must have been pervasive.
For this particular 12th Thursday an additional investigation was performed to determine the cause. The trip time data collected from the RFID tag readers were aggregated into 15-minute time intervals and the time series of the average trip times for the 15-minute time intervals was plotted. The black line in Figure 14 shows the trip time between Readers 2 and 5 on Route 4 northbound for a normal Thursday in October. The trip time variability between these pairs is relatively small with the free flow trip (travel) time being less than five minutes and the congested trip time less than seven minutes. The red line shows a typical Thursday in December. It suggests that under free flow conditions the travel (trip) time should be about five minutes but with more variability than in October. Also, comparing the two typical days on the plot (red and black lines) it can be seen that many of the peaks in the trip times follow the same patterns. For example, there are common peaks at 1:30 PM, 5:00 PM and at 6:45 PM. The difference is that in October the peaks are less pronounced because the weather is less
inclement than in December. Many of these peaks coincide with the start of class schedules at HVCC.

The blue line in Figure 14 also shows the trends in the average trip times for December 13, 2007 which was the 12th Thursday in the study period. On this day there was a snow storm that affected the Route 4 corridor. The snow started at about 11:00 AM and at noon the parallel Interstate I-787 was closed due to an accident. Therefore traffic was diverted from the Interstate to Route 4. The figure shows that by 1:00 PM the traffic on Route 4 reached its peak average trip time of nearly 35 minutes to travel a distance of approximately 2.2 miles; or nearly 4 MPH.

![Figure 14 Incident on 12/13/2007 along Route 4 Corridor](image)

It is also possible to generate other insights from the plots. It is clear that the percentiles vary from one week to the next; and that the higher percentiles are more volatile than the lower ones. In fact, it is the lower percentiles that seem to be good indicators of incidents. For the 6-1 movement (southbound right), except for the 12th Thursday, there is much consistency in all the percentile values; and that day is different because of the snowstorm. Stability in the travel time (the low-valued trip times) otherwise arises because the movement is non-stop from detector 6 to the tech park entrance followed by a right turn into the park followed by arrival at detector 1.
The right turn out of the tech park also has consistent values for the 10th and 50th percentiles. The 95th percentile, however, varies widely, probably because some vehicles have to wait for southbound through traffic before making the right turn / RTOR.

The southbound through is also interesting. The 10th and 50th percentiles are consistent except for the 12th Thursday (when the snowstorm occurred), but the 95th percentile varies widely. This is most likely because vehicles get delayed by the traffic lights.

While the 95th percentile values do vary a lot for R2R pairs 7-3 and 6-3, the overall trends provide guidance about what the travel times are likely to be. By inspection, 600 seconds (10 minutes) appears to be appropriate for 6-3 and 300 seconds (5 minutes) for 7-3. Trying to distinguish the trip times from the travel times, in the case of 6-3 the guidance might be: half of the travelers making the move need 200 seconds (3.33 minutes), so allowing that much time will be OK half of the time, but if you want to be sure you are not late, you should allow 10 minutes – three times that much time. You will be quite early, but you will not be late. In the case of 7-3 the guidance might be similar: half of the travelers making the move need 100 seconds (1.67 minutes), so allowing that much time will be OK half of the time, but if you want to be sure you are not late, you should allow 250-300 seconds (4-5 minutes). Again, you will be quite early, but you will not be late.

The trends for all of the other R2R pairs in the East Greenbush network can be found in Appendix A. The exact details are different in each case, but the trends are similar.

5.2 Individual (User) versus Average (System) Travel Times

Today’s traffic management centers (TMCs) use travel time data that is very different from the individual vehicle travel times that have been studied here. The freeway count stations provide average spot speeds – speeds at a point (not travel times) for short time intervals (typically 5 minutes); and the probe data, if it is available, is received as average travel times aggregated across unknown numbers of probes for TMC segments and short time intervals (again, typically 5 minutes). This means individual vehicle speeds or travel times are never received by the TMC. They are observed in the field (by the individual detectors or by the probe data service provider) but they are not reported back to the TMC.

This means the findings from this study will look very different from the results that would be obtained by looking at detector inputs or probe data from service providers. A much higher level of detail is being examined – individual travel times for individual vehicles making individual trips between pairs of tag readers – not speeds at a point or aggregated averages.

This section illustrates the difference between these types of data feeds. There is richer variation in individual travel times as opposed to the aggregate. This discussion covers the
impacts of aggregating individual observations to create averages, and how travel times relate to spot speeds – how they are similar and yet why they are different. The marked difference between the 95th percentile trip times (or speeds) for the individual vehicle trips and the 95th percentile aggregated average travel times (or speeds) is shown.

It is useful to start with a teaching-based illustration built on a hypothetical situation. Assume that several people (eight in this case) make identical trips across an arterial network from the same origin to the same destination every day; and assume then they share their travel times with one another. Figure 15 presents the results of a 20-day experiment. The left hand side of the figure shows each person’s travel time on each day. It is clear that lots of variation is present. The right-hand sub-figure shows performance measures based on the combined trips. For example, the daily minimum and maximum travel times on right-hand sub-figure are derived from the minimums and maximums in the left-hand sub-figure (for each day). The average is the average travel time for all eight travelers. It is evident that the variation which the individual travelers experience is obscured by the mean travel time. The average travel time ranges between 3 and 6 while the range for the individual users is between 2 and 12; it is more than three times as large (3 versus 10).

![Traveler Travel Times by Day](attachment:traveler_times.png)

Figure 15 Travel Times across Several Days

These same ideas can now be examined in the context of the data from the North Greenbush study. Without loss of generality, the week of August 1, 2007 and R2R reader pair 6-3 (Route 4 southbound) can be used.

To gain a sense of what the tag readers are seeing, consider first the trends plotted in Figure 16. Every set of 50 sequential tag reads has been examined to determine the shortest trip time; the 15th, 50th, and 85th percentile travel time; the maximum, the average; and the span of time over which those 50 travel times was observed (in minutes). Notice that the maximum travel times are huge, representing multi-day trips in some instances (one day is 86,400 seconds); the mean trip time is obviously heavily affected by the large trip times; so is the 85th percentile travel...
time, although much less so; and the shortest trip time, and the 15th, 50th, and 85th percentile trip times cannot be observed because they are so short. As has been said before, it is clearly very important to filter out the long trip times to get a sense of the travel times instead. They are not printed very large because there is not a lot to see except the big trends.

Figure 16: All Trip Time Intensities for Reader Pair 6-3 for August 1-7
Figure 17 shows the same data after a 1200 seconds/mile filter (3 mph or 42 minutes for the trip from Reader 6 to Reader 3) is applied to weed out the very long trip times. Here the “count” is important because it shows how many of the 50 observations remain after the 1200 sec/mi filter is applied.

![Trends in Trip Time Intensity Metrics, Aug. 1](image1)

![Trends in Trip Time Intensity Metrics, Aug. 2](image2)

![Trends in Trip Time Intensity Metrics, Aug. 3](image3)

![Trends in Trip Time Intensity Metrics, Aug. 4](image4)

![Trends in Trip Time Intensity Metrics, Aug. 5](image5)

![Trends in Trip Time Intensity Metrics, Aug. 6](image6)

![Trends in Trip Time Intensity Metrics, Aug. 7](image7)

**Figure 17:** Trip Time Intensities less than 1200 sec/mi for Reader Pair 6-3

Figure 18 shows the exact same data as in Figure 17 but with the maximum value on the vertical axis being set to 300 so the smaller values are more visible.
Trends in Trip Time Intensity Metrics, Aug. 4

Trends in Trip Time Intensity Metrics, Aug. 5

Trends in Trip Time Intensity Metrics, Aug. 6
Figure 18: Trip Time Intensities for Reader Pair 6-3 – Vertical Axis Maximum of 300

It is clear that:

- Imposing the 1200 sec/mi filter helps get closer to real travel time observations. (It still allows 42 minutes to travel from Reader 6 to Reader 3 at 3 mph.)
- The 85th percentile trip time is heavily influenced by trips that involve stops.
- The mean trip time is also heavily influenced by the large trip times.
- The mean is quite different from the 50th percentile value.
- The minimum trip is almost constant across the day.
- This is also true for the 15th and the 50th percentile travel times.
- These low percentile trip times are likely to be good indicators of the travel time.
- The span of time involved in the observations (from the oldest to the newest) is the shortest during the peaks – when the interval between tag reads is the shortest – and it is longer in the mid-day and the early morning and late evening.
- The number of observations with trip time intensities less than the 1200 sec/mi filter is smallest in the late afternoon when work trips and multi-day trip times are being observed. It is greatest late in the evening and earlier in the day.

Having examined these trip time trends, the next thing to do is to see how the average travel times – say from the condition where the 1200 sec/mi constraint is being applied – compare with spot speeds observed in the same area.

Figure 19 shows the distribution of the average trip time intensity when the 1200 sec/mi filter is imposed. It also shows the distribution of space-mean speeds implied by these travel times.
Figure 19: Average Trip Time Intensities and Space-Mean Speeds for Reader Pair 6-3

- The most common average travel time intensity is 90-100 sec/mi (36-40 mph); and there are significant observations at 80-90 (40-45 mph) and 100-110 (33-36 mph).
- The 95th percentile travel time intensity is at 250-260 sec/mi (14 mph) and is not actually shown in the figure – the distribution has a long tail.
- The most common bin for space-mean speeds is 40-45 mph (consistent with the preceding observations – the density functions are based on exactly the same data).
- The next most common bin is 35-40 mph and then 45-50 mph.
- There are a few observations as high as 55-60 mph.

These results can be compared with spot speeds that were collected at various times at the locations of both Readers 3 and 6. The distributions of the individual vehicle speeds are shown in Figure 20.

Figure 20: Individual Vehicle Spot Speeds Observed at Readers 3 and 6

- The two sets of observations are nearly identical.
- These are individual vehicle speeds, not averages, so the variation will be wider than would be observable for the average, but both sets of data are consistent with the observations presented in Figure 19.
- The distribution of values is very similar to the distribution of average speeds derived from the tag data (shown in Figure 19)

Figure 21 shows the distributions that result from transforming the speeds into travel time intensities. Again the results are very similar to the results obtained from the filtered tag data.

![Figure 21: Distributions of Travel Time Intensity based on the Spot Speeds](image)

### 5.3 New York State Fair Analysis

In both 2007 and 2008 the readers were deployed in Syracuse to help facilitate traffic flows at the New York State Fair. The goal was to assess the traffic conditions at and in close proximity to the NYS Fairgrounds. The reason this was important was that a major interstate bridge replacement project was underway near the fairgrounds and it was expected to disrupt traffic for two years. To accomplish the goals, the six wireless solar powered RFID tag readers were deployed to collect and display vehicle travel times in real-time as well as collecting other sources of data such as traffic counts on the surrounding road network.

The tag readers were deployed at six locations with the help of NYS DOT Region 3. During the 2007 NYS Fair the team decided to position the readers to monitor the travel time through the temporary detour when exit 7 for I-690 EB was closed (refer to the Task 34 report for more detail). Since that detour was only in use in 2007 for approximately 1.5 hours the team decided to monitor different travel times during the 2008 NYS Fair (refer to the Task 37 report for more detail). Table 1 shows the various segments for which travel time information was available during the 2008 NYS Fair. The travel time data between the various readers was published in real-time to a website. The website was made available to the NYS DOT officials so the link performance could be monitored. During the 12 day event in 2007 and 2008 there were approximately 43,000 and 52,250 travel recorded travel time pairs recorded respectively (both in real and non-real time).
A sample of the travel time data can be seen in Figure 22, the travel times shown are from the base of the I-690 westbound Exit 7 ramp to the entrance to Gate 6 which is located on the west side of State Fair Blvd. This R2R travel time has a great deal of variation. This is because State Fair Blvd has several traffic lights and many pedestrian crosswalks. The vehicles wishing to go to Gate 6 sometimes must sit in a long queue until they are finally serviced. It is not uncommon for this queue to extend back onto State Fair Blvd. During most times of the day the travel time is normally between 2 and 4 minutes, but when traffic increases, the travel time becomes much less consistent and can extend up to ten minutes. This indicates that at some times of the day the traffic between these two points is moving at less than 10 MPH. If the fairgoers were aware of this congestion in real-time it may be possible to have them change their parking lot preference to one further way, like the Orange Lot. This could be done by carefully crafting a message to display on a VMS. Diverting a percentage of the traffic off of State Fair Blvd. would also increase the safety for the pedestrians crossing the road. A more comprehensive set of travel time plots can be found in Appendix B.

The previous example showed how it was possible to employ real-time travel times to aid in monitoring network conditions, especially in areas that are not well instrumented. Incidents or times of heavy congestion could be monitored and proper actions taken. Figure 23 represents R2R travel times for the path that originates with I-690 westbound at the Bear Street on ramp (both ramp and through traffic) and terminates at the Exit 7 off ramp. In general the travel time between these readers was found to be consistent; however on Sunday August 31, 2008 there was a substantial spike. According to the Help Truck Vehicle Activity Logs, at 10:50 A.M. a rolling roadblock to clear debris was registered for I-690 WB near exit 7.

Table 1 Tag reader pairs

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Real - Time (Y / N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-690 WB @ Bear St (ramp &amp; through)</td>
<td>I-690 Exit 7 WB off ramp</td>
<td>Y</td>
</tr>
<tr>
<td>I-690 WB @ Bear St (ramp &amp; through)</td>
<td>Orange Lot entrance from exit 7 WB</td>
<td>N</td>
</tr>
<tr>
<td>I-690 WB @ Bear St (ramp &amp; through)</td>
<td>Orange Lot entrance from exit 6 WB</td>
<td>N</td>
</tr>
<tr>
<td>I-690 Exit 7 WB off ramp</td>
<td>Gate 6 on SFB</td>
<td>Y</td>
</tr>
<tr>
<td>I-690 EB (west of temp. signal)</td>
<td>Gate 6 on SFB</td>
<td>Y</td>
</tr>
<tr>
<td>I-690 EB (west of temp. signal)</td>
<td>Brown Parking lot</td>
<td>N</td>
</tr>
<tr>
<td>I-690 EB (west of temp. signal)</td>
<td>I-690 EB (in work zone)</td>
<td>Y</td>
</tr>
<tr>
<td>I-690 EB (in work zone)</td>
<td>I-690 WB @ Bear St (ramp &amp; through)</td>
<td>Y</td>
</tr>
<tr>
<td>I-690 EB (in work zone)</td>
<td>Orange Lot entrance from exit 7 WB</td>
<td>N</td>
</tr>
<tr>
<td>I-690 EB (in work zone)</td>
<td>Orange Lot entrance from exit 6 WB</td>
<td>N</td>
</tr>
</tbody>
</table>
When this spike was originally noted on the travel time website the team accessed the online video images to see if there was a problem. Figure 24 has a series of traffic camera images showing the traffic backups through the work zone leading to the fairgrounds. Although the initial incident was cleared relatively quickly the effects lingered until approximately 3:00 P.M., nearly four hours after the initial incident.
Figure 24 8/31/08 accident on I-690 WB
6 Key Findings and Conclusions

This report has described a series of experiments with a portable RFID tag reader intended to provide travel times for traffic management. The work was part of the Electronic Toll and Traffic Management (ETTM) project at Rensselaer Polytechnic Institute (RPI) sponsored by the New York State Department of Transportation (NYSDOT) and the Federal Highway Administration (FHWA).

Multiple wireless solar powered E-ZPass tag readers were deployed and tested in North Greenbush and Syracuse in upstate New York. The wireless, solar powered E-ZPass tag readers were developed and deployed by RPI with Mark IV Industries as the industrial partner. Other academic partners included North Carolina State University and Polytechnic Institute of New York University. This tag reader is comprised of Mark IV’s low powered mGate™ tag reader, antenna, solar panel, batteries and charger, enclosure and a pocket PC (PPC).

The readers were deployed from July 2007 until early January 2008 in both the Capital District ITS Testbed located in North, Greenbush, NY and at the New York State Fair in Syracuse, NY. The time it took to setup the trailer from when it was dropped at the site until the device was fully functional and transmitting data was typically in the range of 20 – 30 minutes. The team was fortunate 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. It performed well.

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 damaging the coaxial components but these were relatively rare and with the proper weatherproofing eliminated. In fact, the last minute change to use a PPC and Bluetooth proved to be tolerable for the solar power system. In addition, there was no communication interference with the mGate™ reader.

The most significant problems were:

- **The Pocket PC (PPC).** It claimed to be one of the more advanced devices on the market at the time of deployment. However, the PPC was the result of most of the failures while the system was deployed. It would occasionally stop functioning for no apparent reason and need to be reset and restarted. Using a different PPC would eliminate this problem.

- **The solar panels.** The solar panels were not large enough to always keep the batteries charged. This is not because the solar panels failed but rather because they were not designed to be used in the middle of winter. The study team originally did not expect the detectors to be deployed in that time frame, but because the opportunity presented itself, the tests were conducted. Not surprisingly, it was found that the solar panels and or the batteries would have to be larger for that condition.
Data were collected from the US Route 4 corridor, a two-lane arterial in North Greenbush, NY from July 2007 until January 2008. In close proximity to the test sites there were a community college and technology park accessed by Route 4. After eliminating all errors in the data, an average of 99.10% of the records were used to estimate travel times and the efficiency of the readers.

The most interesting finding was that there was a descending pattern in the R2R (reader-to-reader) travel times observed each day. Moreover, the descending pattern arose because the longest R2R times were observed early in the day, starting at upwards of 10 hours, and then getting shorter as the day progresses. More specifically, until about 5:00AM (0.2 days) very few R2R times are observed. Then much shorter times appear, probably produced by people going to work. Sprinkled in are much longer times, up to 30,000 seconds, probably for people going work at places along Route 4. An illustration is someone entering the study about 7:00AM (0.3 days) and then leaving about 4:00PM, 30,000 seconds later (9 hours). These long R2R travel times get shorter as the day progresses until they all but disappear at about 4:00PM (0.7 days). From then on, the R2R times are all relatively short. The magnitude of the large R2R travel times vary slightly from day to day, the descending pattern is always present.

A major implication from this is that estimating R2R times for arterials will not be as easy as for freeways. On freeways, the stopping opportunities do not exist, so the travel times are always short unless incidents occur; so analysis and prediction/estimation is relatively straightforward; but not so for arterials.

This finding also leads to an observation that AVL systems will provide better information about R2R travel times than AVI systems will. With AVL systems, it will be possible to filter out the travel times for the extended trips.

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 a lot 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 R2R 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;
• R2R 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 R2R 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.

That having been said, while the 95th percentile value does vary a lot; 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 reviewed so far, one can make statements like: half of the travelers for this R2R 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.

In sum, it is clear that these wireless, solar powered tag readers do work. They function well under a wide variety of environmental conditions and do a good job of capturing passing tags. A better PPC (personal PC) could be used to 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 a lot of cloud cover; but those are design improvement details. The technology is sound, functional, and useful.

Moreover, the data from the detectors is very valuable. The data can be used to estimate travel times, watch for incidents, monitor travel time reliability, etc. The data are not quite as valuable as that provided by AVL equipped vehicles, where the entire vehicle trajectories can be observed, but compared with 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, the AVI systems are much better; they provide a major improvement in system observability.
7 References
