ITS INNOVATIVE PROJECT
ARTERIAL TRAVEL TIME MONITORING SYSTEM
USING BLUETOOTH TECHNOLOGY

Final Evaluation Plan

Submitted to:
Minnesota Department of Transportation
(Mn/DOT)

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1.0 BACKGROUND

The Arterial Travel Time Monitoring System Using Bluetooth Technology project along CSAH 81 was selected by the Minnesota Department of Transportation (MnDOT) as part of its 2009-2010 ITS Innovative Idea program. The goals of the project are:

- To provide an operational test of an end-to-end solution that will result in accurate and reliable information on arterial travel times.
- To evaluate the results with respect to actual travel times and other various parameters (e.g., sample size).
- To demonstrate how the travel time information may be used as a performance measure for arterial traffic management and operations.
- To demonstrate how the data might be disseminated as traveler information (e.g., displayed on Google maps).
- To derive practical deployment guidelines as well as a nucleus for subsequent expansion of the technology in Hennepin County, in Minnesota or in other states.

The Bluetooth readers used for this project, known by the name “StreetWAVE” are manufactured by Savari Networks, LLC. The StreetWAVE readers read MAC addresses from Bluetooth devices used or contained within vehicles traveling along CSAH 81. Each reader contains a Bluetooth antenna that captures MAC addresses, which are then sent to a server operated by Savari over a 3G wireless network. The server matches the addresses and their respective time stamp to the same MAC address from any Bluetooth node along the corridor. A web-based user interface provides travel time information and graphical displays/outputs from the corridor data.

In May 2010, eight StreetWAVE units were placed along CSAH 81 at six (6) intersections shown below in Figure 1. The evaluation of the Arterial Travel Time project began in May 2010 and will be completed by the end of December 2010.
2.0 EVALUATION PLAN COMPONENTS

The focus of the evaluation plan is to document the process that will be used to determine the accuracy and potential value of the collected information. In other words, the purpose of the evaluation plan is to determine whether the Arterial Travel Time Measurement System – and the concepts on which it is based – adequately address the “problem statement” posed by the project, specifically: “to obtain reliable and accurate travel time information along an arterial network in a cost-effective manner”. The approach and process for evaluating the Arterial Travel Time Monitoring System Using Bluetooth technology includes the following activities:

- Data Collection Activities

“Floating car” travel time runs will be performed along both directions of the arterial for two consecutive weekdays – a Tuesday/Wednesday or Wednesday/Thursday – for a period of twelve hours per day (i.e., three hours during the AM peak, six hours during the off-peak, and three hours during the PM peak). Travel time studies and data gathering will be performed three times during the course of the project. The first set of travel time runs will occur prior to...
the deployment of the system in order to validate future travel times. Two sets of travel times will also be conducted after the system has been deployed, once in the summer and once during the fall.

The following information will be recorded for each individual run:

- Starting point (intersection) and time (day: hour: minute: second)
- Time (day: hour: minute: second) the stop bar of each of the Bluetooth-equipped intersections is reached
- Any operational anomalies during the travel time run (e.g., signal failure/on flash, incident).

Volume (tube) counts (by direction) will be collected at each location along the arterial during the same period as the travel time runs are conducted.

- **Data Input/Analysis**

  The collected information will be input into a preferred database application for analysis, providing information on the travel time per link for each run, the average travel time for each link per period (including standard deviation), and the average travel time for each link per time period over the three day evaluation period (including standard deviation).

  The raw travel time data collected by the system will be summarized, using the same format, links (by direction), times, periods, days, etc. as the travel time runs. This will be done in order to determine the capture rate and statistical sample size necessary for a representative sampling of Bluetooth device identification along the corridor during the travel time data collection process.

- **Data Comparison**

  The information collected by the system will be compared and analyzed with the information obtained from the travel time runs, identifying differences between the two, the nature of the variations, any consistencies or inconsistencies of the results, etc.

  Statistical information will be developed regarding the capture rate and sample size (i.e., number of matched pairs of MAC addresses per link compared to the total volume). This information will be used to correlate with the accuracy of the travel time information.

  Identification of the appropriate “data smoothing” parameters in order to minimize differences found between the information collected by the Bluetooth system and the actual travel time data. (Note – The proposed system includes a user-definable data smoothing feature, such that x-percent of the reads with the highest travel times, and y-percent of the lowest travel times, are removed from the data used in subsequent aggregation and displays). In addition to
identifying the optimum parameters in this regard, the logic behind selecting these parameters will also be considered.

3.0 DATA COLLECTION PROCESS

3.1 TRAVEL TIME RUNS

Travel time runs are to be performed for a twelve hour period over two consecutive weekdays between 6:30 AM and 6:30 PM. The runs will be recorded in three time periods: the AM Peak (6:30 AM - 9:30 AM), Off Peak (9:30 AM - 3:30 PM), and PM Peak (3:30 PM – 6:30 PM). The travel time runs will be performed at several key points during the study using the “floating car” technique, where the driver attempts to pass a vehicle along the corridor each time another vehicle passes the “floating” car. This technique is described in the Manual of Traffic Engineering Studies (4th Edition) and the summary of data will be consistent with this manual.

Travel time runs will be conducted using PC Travel, GPS-based software. This software calculates travel time run time and average speeds (by time period) along the CSAH 81 corridor. Average travel times will be presented in a table similar to the one shown below in Table 1.

<table>
<thead>
<tr>
<th>Node 1</th>
<th>Node 2</th>
<th>Average Travel Time May</th>
<th>Average Travel Time September</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Northbound Direction</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36th Ave. NB</td>
<td>42nd Ave. NB</td>
<td>AM</td>
<td>Off-Peak</td>
</tr>
<tr>
<td>42nd Ave. NB</td>
<td>63rd Ave. NB</td>
<td>AM</td>
<td>Off-Peak</td>
</tr>
<tr>
<td>63rd Ave. NB</td>
<td>Green Haven NB</td>
<td>AM</td>
<td>Off-Peak</td>
</tr>
<tr>
<td><strong>Southbound Direction</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green Haven SB</td>
<td>71st Ave. SB</td>
<td>AM</td>
<td>Off-Peak</td>
</tr>
<tr>
<td>71st Ave. SB</td>
<td>Bass Lake Rd. SB</td>
<td>AM</td>
<td>Off-Peak</td>
</tr>
<tr>
<td>Bass Lake Rd. SB</td>
<td>36th Ave. SB</td>
<td>AM</td>
<td>Off-Peak</td>
</tr>
</tbody>
</table>

On August 19-20, 2009, travel time runs were conducted along the study corridor in order to determine pre-study average traffic speeds. This information was averaged by corridor link and is presented in Table 2.
TABLE 2: PRE-DEPLOYMENT CSAH 81 TRAVEL TIMES

<table>
<thead>
<tr>
<th>Node 1</th>
<th>Node 2</th>
<th>Average “Before” Travel Times August 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Segment (NB)</strong></td>
<td>AM (sec)</td>
<td>PM (sec)</td>
</tr>
<tr>
<td>36th Ave. NB</td>
<td>42nd Ave. NB</td>
<td>110</td>
</tr>
<tr>
<td>42nd Ave. NB</td>
<td>63rd Ave. NB</td>
<td>313</td>
</tr>
<tr>
<td>63rd Ave. NB</td>
<td>Green Haven NB</td>
<td>333</td>
</tr>
<tr>
<td><strong>Segment (SB)</strong></td>
<td>AM (sec)</td>
<td>PM (sec)</td>
</tr>
<tr>
<td>Green Haven SB</td>
<td>71st Ave. SB</td>
<td>119</td>
</tr>
<tr>
<td>71st Ave. SB</td>
<td>Bass Lake Rd. SB</td>
<td>228</td>
</tr>
<tr>
<td>Bass Lake Rd. SB</td>
<td>36th Ave. SB</td>
<td>272</td>
</tr>
</tbody>
</table>

3.2 DIRECTIONAL TUBE (VOLUME) COUNTS

Directional tube counts will be placed at pre-selected locations along CSAH 81 at the same time the travel time runs are being performed to determine traffic volumes at each node. This will be done in order to determine what percentage of the Average Daily Traffic (ADT) count the StreetWAVE device is able to identify at each location.

4.0 DATA AGGREGATION AND COMPARISON METHODOLOGY

4.1 STREETWAVE DEVICE DATA

4.1.1 STREETWAVE MAC ADDRESSES

The StreetWAVE device reads MAC addresses of Bluetooth-enabled devices to calculate travel times for vehicles that are traveling along an arterial corridor. Bluetooth devices located within the vehicle (whether operational on a laptop, a cell phone, or another intelligent device or installed as part of the vehicle’s platform) will provide unique addresses or signatures that can be read by the StreetWAVE unit as the device moves into and through the reader’s operational zone. To protect the privacy of drivers, Savari has created a simple algorithm to mask actual MAC addresses. The MAC address of Bluetooth devices is inherently anonymous and cannot be traced back to the current owner or even the device equipped with the Bluetooth technology. The additional masking of addresses adds another layer of data security. To ensure the accuracy of the demonstrated system, a Bluetooth device will be used during each set of travel time runs that are to be performed along the CSAH 81 corridor for this project. The Bluetooth
device’s MAC address will be tracked by the consultant after it is converted using Savari’s algorithm for device recognition in the field.

Once the travel time runs are completed, data will be analyzed from the Savari web interface (http://minneapolis.savarinetworks.com). This data can be found at this web address by selecting “Travel Times” on the left sidebar on the home page, and selecting the desired study dates. The data downloaded from the interface is provided within a few seconds. To better understand the information’s relevance to traffic conditions, the travel times will be converted to segment speed by taking the length of the segment divided by the time it takes to traverse that segment length.

\[
\text{Segment Speed (mph)} = \frac{\text{Segment Length (ft)}}{\text{Time (s)}} \times \frac{3600}{8280}
\]

**Figure 2** displays the speed limit changes along CSAH 81.

**FIGURE 2: SPEED LIMIT CHANGES ALONG CSAH 81**
4.1.2 *StreetWave Data Sampling*

When collecting travel times it is important that the data is of a sufficient sample size. If the sample size is too low, the data may prove to be inconsistent with actual field conditions. Sample size can be calculated from the following parameters: confidence level, margin of error, and population size. With traffic ranging from 10,000 to 25,000 vehicles per day along the corridor and speeds ranging from 20 mph to 60 mph, substantial fluctuations in travel time results are expected. Statistical sampling consistent with the *Manual of Traffic Engineering Studies* (4th Edition) along with other statistical calculations will be used to compare field travel time to the anticipated large sample set of Bluetooth matches.

4.2 *Data Comparison*

Once the data from the travel time runs and the StreetWave interface have been gathered, the data will be compiled into a table where one set of data can be directly compared to the other.

5.0 *Data Filtering and Smoothing*

5.1 *Data Filtering*

When collecting MAC address reads at a measurement location, several situations may occur:
- A specific MAC address is recorded once. In that case, that address is used for travel time measurements
- A specific MAC address is recorded several times within a short time frame (e.g. within two minutes). This could occur due to the fact that the Bluetooth reader detects Bluetooth enabled devices within a certain radius of the antenna. A Bluetooth device may likely be detected several times in this situation, especially at signalized intersections where vehicles are expected to decelerate and possibly wait for the next green phase to pass through the intersection during that time. In order to correctly use this data for processing, all records would be collected, and the calculation of travel times would allow for the selection of four different calculations:
  - **First-First** (travel time from the first measurement at each location, which will include queuing at the first intersection).
  - **First-Last** (travel time from the first measurement at the first to the last measurement at the second location, which will include queuing at both intersections).
  - **Last-Last** (travel time from last measurement at the first to the last measurement at the second location, which will include queuing at the second intersection).
  - **Last-First** (travel time from the last measurement at the first to the first measurement at the second location, reducing the impact of queuing at both locations when measuring travel times).
A specific MAC address is recorded several times with a larger time gap (e.g. several hours). This can occur when a driver with a Bluetooth-enabled device passes at different times. In this case, the different MAC address reads are considered separately.

One other important area is the elimination of outliers. While the majority of drivers will travel at a speed within a certain range (based on current traffic congestion), there will always be vehicles driving slower or faster than the majority of drivers. On an arterial, driving times are affected by a variety of factors – a driver may stop temporarily on the arterial to enter a store, get gas etc. – or just stop and check his or her email or look at a navigation screen. In any case, the distribution of travel times along an arterial road is more complex than on freeways, based on the potential for a variety of driver/traffic behaviors.

Eliminating outliers is important, as the inclusion of excessive travel times due to a few ‘shoppers’ will skew the mean, thus rendering the resulting information less meaningful. Outliers can be eliminated using simple mathematical calculations. These can include the percentage of vehicles beyond or below the mean, the use of standard deviation measures, or the use of absolute values. A visual check of calculated travel times on the web display allows for a simple validation of which travel times should be excluded.

5.2 DATA SMOOTHING

Raw travel times are valuable, as they demonstrate how individual drivers travel from Point A to Point B. Observing the distribution of travel times is also valuable in order to assess the effect of external factors (shopping etc.) on people’s travel behavior. However, in order to provide relevant information to the traveling public or operators of the transportation system, average values are important. Overlaying the raw with smoothed data provides valuable insight with how a few large travel times (the ‘outliers’) affect the average travel times. Smoothing factors should allow for different granularities (e.g. 5, 10, 15, 30 minutes).

6.0 WEB INTERFACE

The web interface allows users to access raw data captured by the StreetWAVE devices. This interface can be found at http://minneapolis.savarinetworks.com. The interface allows the user to view device information (including location, IP address, and operational status), travel times, and location measurements. Data from the interface will be used to compare against the travel time data collected in the field.
7.0 NEXT STEPS

The evaluation plan will be used to create the final report tables and calculations in order to ultimately draw conclusions regarding the project’s objectives. Data analysis will be completed and additional statistics will be presented in the final report that will help describe the overall evaluation process and operation of the system.

A final report will be prepared that documents the project, the approach and the results of the system.