Wisconsin DOT Travel Time Technology Evaluation (T3E)

Analysis Plan

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1. Task Introduction

This is a detailed analysis plan to determine how best to compare all of the travel time technologies being studied in the Travel Time Technology Evaluation (T3E).

As part of this analysis plan, a detailed literature review was completed. This review looked at previous studies analyzing travel times. This will include looking at related efforts and past efforts including the 2008 AirSage/INRIX evaluation report, the TOPS Bluetooth traffic detector comparison study completed in 2013, and recent Great Lakes Regional Transportation Operations Coalition (GLRTOC) work with Bluetooth and probe data including work completed in Janesville comparing Bluetooth, probe data, and NPMRDS data. The literature review is included in Appendix B.

Next, specific routes/segments are chosen based on data availability and relevancy to the project. Time periods have also been chosen as appropriate for the comparison.

The process for data source retrieval will be determined for all data sets including:

- Purchased TomTom GPS-based probe data and additional interstate TomTom data;
- The free FHWA National Performance Management Research Data Set (NPMRDS);
- Bluetooth detection maintained by WisDOT or GLRTOC;
- Microwave detection;
- Inductive loops, available via WisTransPortal; and
- Automatic Traffic Recorders (ATRs).

Statistics and metrics are chosen based on the literature review and the adaptation of WisDOT travel time quality assurance, quality control (QAQC) process.

This project does not include field data collection such as travel time runs.

See Appendix A for the project management timeline for this project.

2. Background

The overall purpose of the T3E project is to understand the quality of probe data and appropriate use applications. In conjunction with the I-39/90 expansion project and the Verona Road project, a real time data feed has been purchased by WisDOT with expansion and renewal options up to seven years covering Rock and Dane counties. This evaluation will compare the TomTom data with other travel time calculation technologies to determine which technology is most appropriate. It is possible that certain technologies will work better on different types of highways and in rural/urban areas.

2.1. Reasons for Evaluating Technologies

WisDOT has many dynamic message signs (DMS) stating travel times to aid commuters and other travelers throughout the state in typically congested areas. Roadway users expect that these times are accurate, and if the times are not accurate, users will lose faith in the system. In situations where delays are expected, accurate freeway and alternate route travel times are imperative. This allows drivers to divert onto the alternate route when the route offers a faster travel time, thus maximizing the capacity of the built highway network and minimizing user delay cost.

With the onset of connected vehicles, travel time information can be made available in the vehicle as part of the heads-up display. This will result in roadway users expecting the most precise travel times available in all situations.

In order to provide these travel times, WisDOT is performing this evaluation to

- Compare arterial versus freeway travel times
- Compare long term versus short term travel times (cases such as alternative routes for construction projects).
- Compare costs of acquiring and maintaining data
- Compare difficulty of accessing and processing data sources
- Determine other uses of travel time data
- Integrate technologies into the transportation systems management and operations (TSM&O) decision process for detection

The better WisDOT understands the quality of data available now, the better the accuracy of travel times that will be available now for use on installed DMS and in the near future in the roadway users' vehicles.

2.2. Existing Travel Times

WisDOT travel time information is currently calculated based on speed data collected by a variety of traffic data detection devices located along a road corridor that is then integrated into the Advanced Traffic Management System software (ATMS) used by WisDOT.

WisDOT has been using speed data from in-pavement loops and microwave detection devices to calculate travel times for over a decade. WisDOT recently began using Bluetooth detection devices in 2014 to provide speed data for arterial routes in the Southeast Region and for freeway routes in the Southwest Region. Bluetooth data processed by C2Web software from Drakewell at the STOC was then integrated into WisDOT's ATMS software around the same time and can now be used as another data source for travel time calculation.

2.3. Existing Technology for Study

WisDOT is currently comparing three TomTom applications including the Traffic Flow Viewer (TFV) for real-time traffic, the Live Traffic Archive (LTA) for viewing all historic data in 1-minute intervals, and the Custom Travel Time (CTT) tool for viewing travel times on custom routes. In conjunction with these tools, data will be collected and analyzed from WisDOT's current sources (automatic traffic recorders (ATRs), microwave detectors, and loop detectors) as well as other emerging data sources (Bluetooth detectors and the National Performance Management Research Data Set (NPMRDS)).

Most data sources include historic data as well as real-time information. The TFV tool from TomTom and the NPMRDS do not include real-time information and are used for verification purposes only.

Table 1 summarizes the technologies to be analyzed for this project along with their availability.

Table 1. Travel Time Technologies used in the Travel Time Technology Evaluation (T3E)

Technology	Time Interval (min)	Availability Period	Access Time	Availability Ends	Data Format
TomTom (CTT)	15	January 1, 2008, (0:00) – Present	Average	June 27, 2016 (19:00)	KML, XLS, SHP
TomTom (LTA)	1	April 14, 2015, (8:00) – Present	Difficult	January 29, 2017 (19:00)	Protobuf (OpenLR)
NPMRDS	5	July 1, 2013, (0:00) – Present	Average	June 30, 2017 (23:33)	Database (CSV)
Bluetooth	1	Varies by site (see Table 3)	Average	Varies by site (see Table 3)	XLS
ATR	60	January 1, 2014, (0:00) – Present	Average	N/A	Database (CSV)
Microwave	1	January 1, 2012, (0:00) – Present	Average	N/A	CSV
Loop	1	January 1, 2012, (0:00) – Present	Average	N/A	CSV

2.4. Other Technologies

Many technologies exist to calculate route travel times. Although some of these are used in this study, there are many that will not be compared. For completion purposes, all major methods are listed here. These are detailed in Section 2 of the Literature Review and summarized here.

2.4.1. Point Sensors

A point sensor measures the presence and speed of vehicles that travel by the location point where the sensor device is deployed. These include loop detectors, microwave detectors, and ATRs. These devices are generally used for volume, speed, and occupancy measurements. However, travel times can be measured between two devices using either the half-distance approach or the minimum speed approach as outlined in the literature review.

2.4.2. Video and License Plate Readers

Travel time can be measured by automatic plate recognition systems (APRs). The measurement requires at least two fixed APR systems on the road. When a vehicle passes by the first APR system, the video recorder of the APR will read its plate number. Then when the same vehicle passes through the second APR system, its plate number will be recorded again. Finally, the server will match the plate numbers and their time stamp tags. By matching the time stamp and measuring the distances between the set of APR systems, the travel time and travel speed of the vehicles could be measured.

2.4.3. Radar

Radar detectors can collect velocity, flows, and occupancy data when they are deployed along the roadside. Since the radar detection is strongly impacted by the road environment, radar is more widely implemented on rural highways rather than in urban areas. Although radar is suitable with massive data collection, the collected data has low accuracy.

2.4.4. Bluetooth

Bluetooth detectors scan the area range and check if any Bluetooth enabled device are detected. Once the vehicle equipped with Bluetooth devices drive into the detection range of a Bluetooth reader, enter and exit time stamps of the devices are recorded. Therefore, travel time and travel speed can be determined between points on the roadway.

The Bluetooth data gives a straight measurement of travel time between pairs of scanners. The data includes the “duration” of time required for the vehicle to pass the range detection limits of the Bluetooth scanner. Thus, Bluetooth data can give the entry and exit timestamp for each of the detectors which provides the duration of each Bluetooth device.

2.4.5. Wi-Fi Technology

Wi-Fi Technology can be used to measure the travel time of vehicles when the location of the probe vehicle and its distance to the next Wi-Fi spot is known. However, the measurement is affected by the noise impacting the localization of the car. Therefore, this technology is accurate enough for route planning, but it does not work well for individual road section estimation.

2.4.6. High-Frequency GPS Data

High-frequency GPS is a method where the probe vehicle can send GPS information every few second or each second (no more than 10 seconds). This aspect makes the data the most accurate for travel time estimation. However, the number of GPS enabled probes may limit its application. There are also some map matching problems for the complex environment such as roundabouts or intersections. This is the general strategy used by providers such as TomTom, Inrix, HERE, Google, and Waze; although they do use a variety of other probe data sources that are proprietary and thus not fully disclosed.

2.5. Current Wisconsin Travel Time Information Sharing and Users

Travel times in Wisconsin are currently available through 511 Wisconsin online and through an XML feed. Access to the 511 site is open to the public. The XML feed is available by subscription with subscribers including media outlets, researchers, and construction project teams. In particular, the Zoo Interchange team in Milwaukee is using travel time records for performance evaluation.

With the onset of connected vehicle technologies, the same travel times disseminated through 511 could eventually be displayed real-time on vehicle's heads-up display units, which will vastly expand the routes in which travel times are made available.

The Madison Area Transportation Planning Board, Madison's Metropolitan Planning Organization (MPO), currently is working with WisDOT to obtain Bluetooth travel time information. Research has been conducted at the University of Wisconsin-Madison and is in preliminary phases at the University of Wisconsin-Milwaukee using a combination of WisDOT Bluetooth detectors and detectors used by GLRTOC on DMSs throughout the state on major corridors.

3. Study Area and Period

3.1. Data Comparison

The following items will be considered when comparing data in this study:

- Data availability and data source variability
- Ease of access and user interface
- Latency for real time application
- Reliability
- Ability to archive data (for public inquiries, QA/QC, or performance reporting)
- Durability of equipment (for hardware maintenance)

3.2. Selected Routes

Eight routes have been selected to complete the study. The routes offer a mix of rural and urban as well as freeway and arterial. This will allow for comparison between freeways and arterials, as freeway travel times are generally more precise than for interrupted flow facilities. These routes are shown in Table 3 and Figure 1. TomTom and NPMRDS data is available on all routes and Bluetooth data is available on multiple routes. Specific segments within these corridors will be chosen for statistical analysis. Note that the WIS 73 route is highlighted in Figure 1 with a circle, as the route is short and difficult to see.

Table 2. Selected Routes for the Travel Time Technology Evaluation with Data Types

Corridor	Corridor Start/End	Location	Route Type	Data Types
US 12/18	I-39/90 to WIS 73	East of Madison	Rural Arterial	TomTom, NPMRDS, Bluetooth
US 14 M (Madison)	US 12/18 to County MM	Fitchburg	Urban Freeway	TomTom, NPMRDS, Bluetooth, ATR
County M	US 18/151 to County MM	Fitchburg/ Verona	Rural Arterial	TomTom, NPMRDS
US 14 J (Janesville)	I-39/90 to WIS 140	East of Janesville	Rural/Urban Arterial	TomTom, NPMRDS, Bluetooth, ATR
WIS 73	I-39/90 to WIS 106	Albion	Rural Arterial	TomTom, NPMRDS, Microwave
E Washington (US 151)	Blair St to Portage Rd	Madison	Urban Arterial	TomTom, NPMRDS, Bluetooth, ATR
I-39/90	IL Border to I-94	Dane/ Rock	Rural Freeway	TomTom, NPMRDS, Bluetooth, ATR, Microwave
US 12	I-39/90 to Parmenter St	South of Madison	Urban Freeway	TomTom, NPMRDS, Bluetooth, ATR, Microwave, Loop

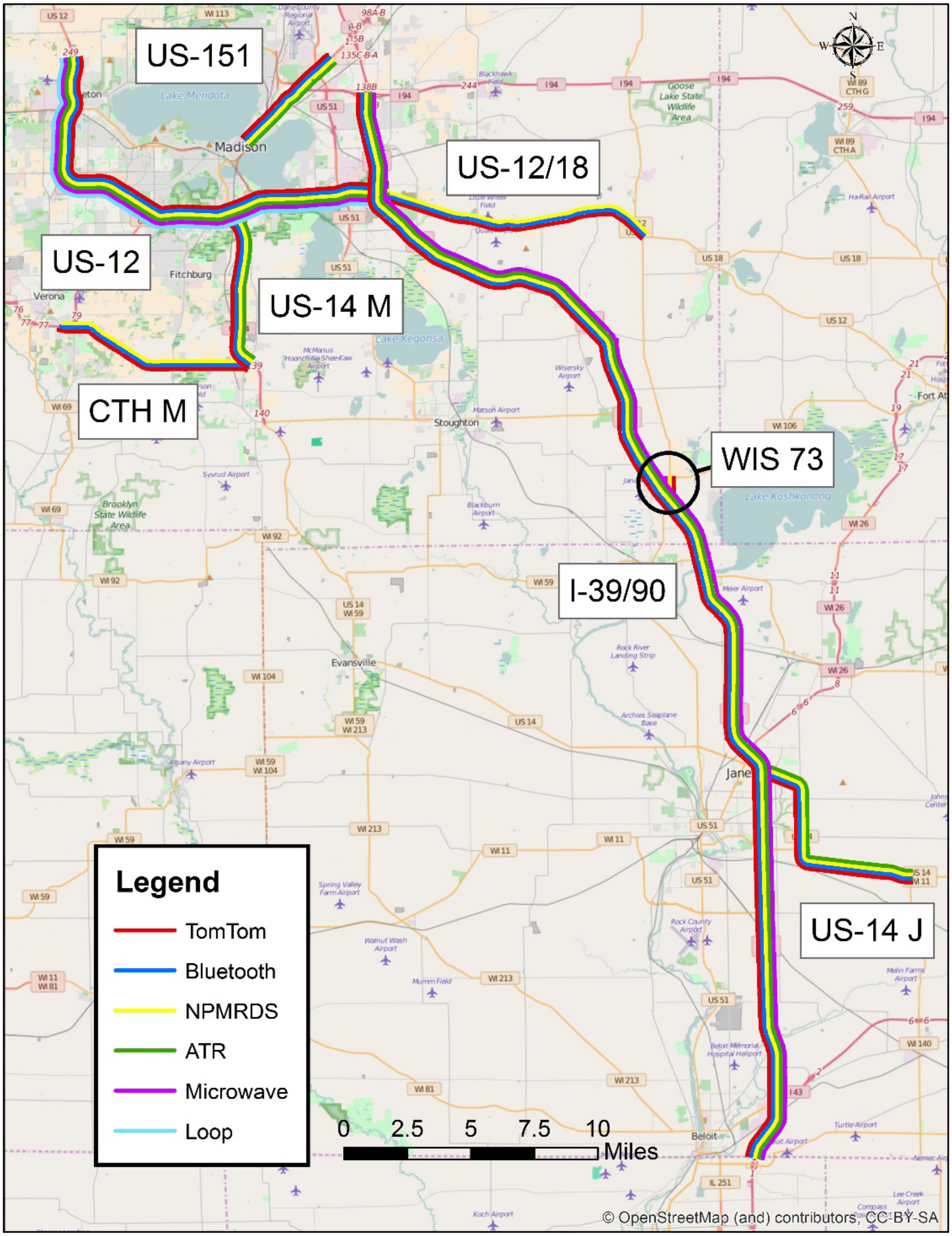


Figure 1. Travel Time Technology Evaluation (T3E) Route Overview Map

3.3 Study Time Periods

To make sure that statistical comparisons are as consistent as possible, specific dates and times have been chosen for the analysis. These dates are limited to the intersection of data availability and thus are different depending on the corridor. Time periods chosen for the study are shown in Table 3.

Specific study time ranges within the chosen time periods will be used and comparisons will be made within the corridor and cross-corridor depending on highway classification. The time ranges used are:

- AM Rush, 7:00am-9:00am (weekdays)
- AM Peak, 7:30am-8:30am (weekdays)
- PM Rush, 3:00pm-6:00pm (weekdays)
- PM Peak, 4:30pm-5:30pm (weekdays)
- Weekday Daytime, 6:00am-6:00pm
- Weekend Daytime, 7:00am-7:00pm
- Nighttime, 10:00pm-4:00am
- Holiday Travel (Memorial Day or Independence Day)

Table 3. Selected Time Periods for Study by Corridor

Corridor	Corridor Start/End	Available Period	Chosen Periods
US 12/18	I-39/90 to WIS 73	04/14/2015 to Present	05/01/2015 to 05/31/2015 and 05/01/2016 to 05/31/2016
US 14 M (Madison)	US 12/18 to County MM	04/14/2015 to Present	05/01/2015 to 05/31/2015 and 05/01/2016 to 05/31/2016
County M	US 18/151 to County MM	04/14/2015 to Present	05/01/2015 to 05/31/2015 and 05/01/2016 to 05/31/2016
US 14 J (Janesville)	I-39/90 to WIS 140	04/14/2015 to 11/02/2015	05/01/2015 to 05/31/2015
WIS 73	I-39/90 to WIS 106	04/14/2015 to Present	05/01/2015 to 05/31/2015 and 05/01/2016 to 05/31/2016
E Washington (US 151)	Blair St to Portage Rd	06/10/2016 to Present	07/01/2016 to 07/31/2016
I-39/90	IL Border to I-94	06/05/2015 to Present	07/01/2015 to 07/31/2015 and 07/01/2016 to 07/31/2016
US 12	I-39/90 to Parmenter St	04/15/2015 to 05/04/2015	04/15/2015 to 05/04/2015

4. Analysis Steps

4.1. Data Acquisition and Storage

Data will be acquired from all sources using various means. Data that is less time consuming to access (e.g., NPMRDS) will be acquired for all times that the data is available. Data that is more time consuming to access will be acquired only for the times that are specified in Section 3.

This section summarizes the data available and access basics for each data source. A complete download and processing guide for the LTA will be included in Task 3 of this project.

4.1.1 TomTom LTA (Live Traffic Archive)

Access Point: TomTom, http://trafficstats.tomtom.com/
Access Settings: Date, hour, and minute (range)
Interval Size: 1 minute
Dates Available: April 14, 2015 (8:00) - Present
Routes Available: Most freeways and arterials as well as some major collectors
Link Type: OpenLR
Data Format: Protocol Buffer / OpenLR
Information Provided: Average Speed, Travel Time
Data Access Screen: See Figure 2

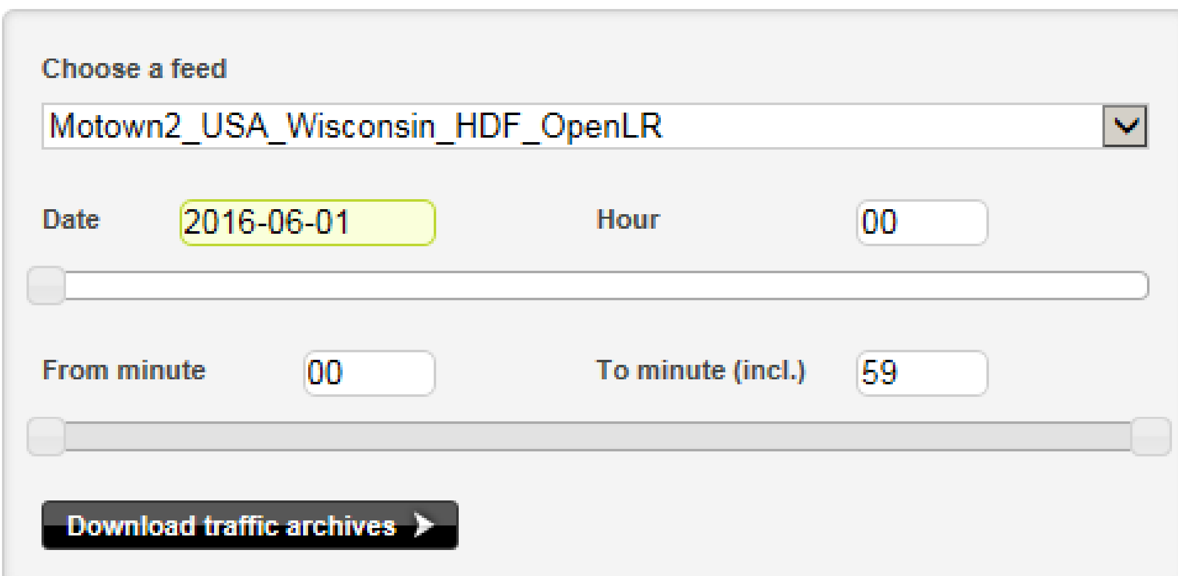


Figure 2. Data Access Screen for TomTom Live Traffic Archive Tool

4.1.2. TomTom CTT (Custom Travel Times)

Access Point: TomTom, http://trafficstats.tomtom.com/
Access Settings: Routes, dates, and time sets
Interval Size: 15 minutes
Dates Available: January 1, 2008, (0:00) - Present
Routes Available: Most freeways and arterials as well as some major collectors
Link Type: TomTom Segment Identifiers
Data Format: Google KML, ArcGIS Shapefile, and Excel Spreadsheet
Information Provided: Average/Percentile Speeds, Average/Median Travel Time
Data Access Screen: See Figures 3, 4, and 5

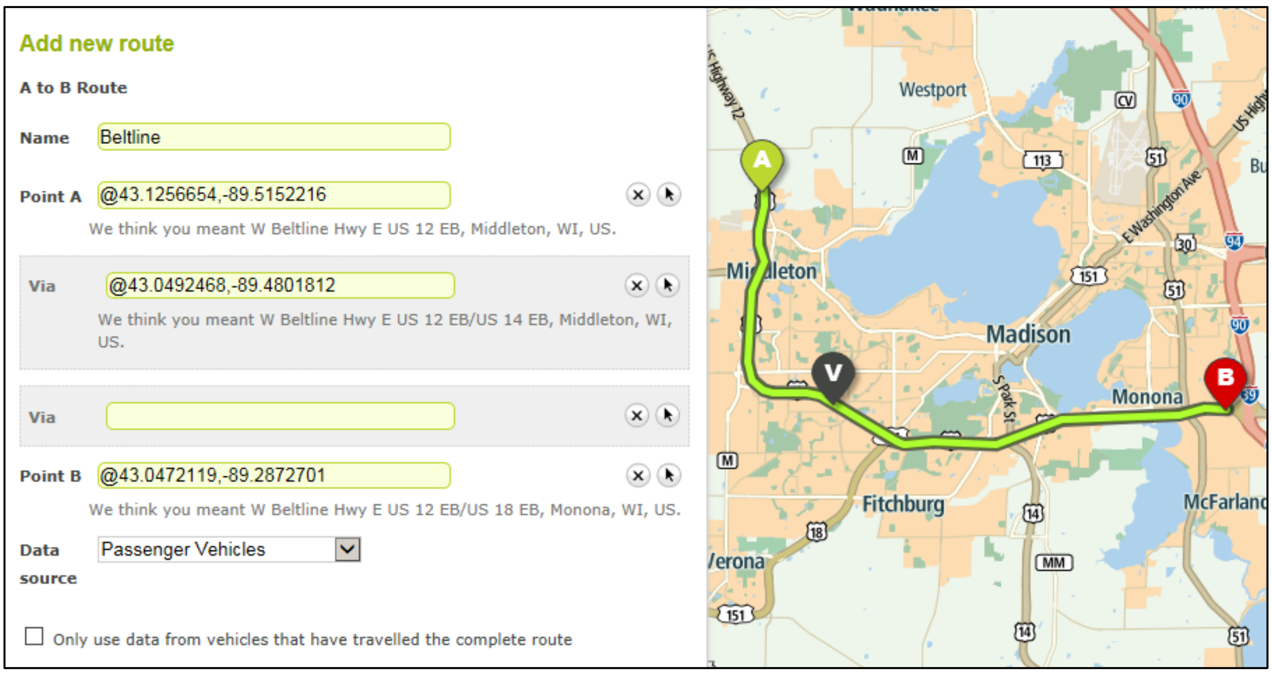


Figure 3. Data Access Screen (Routes) for TomTom Custom Travel Time Tool

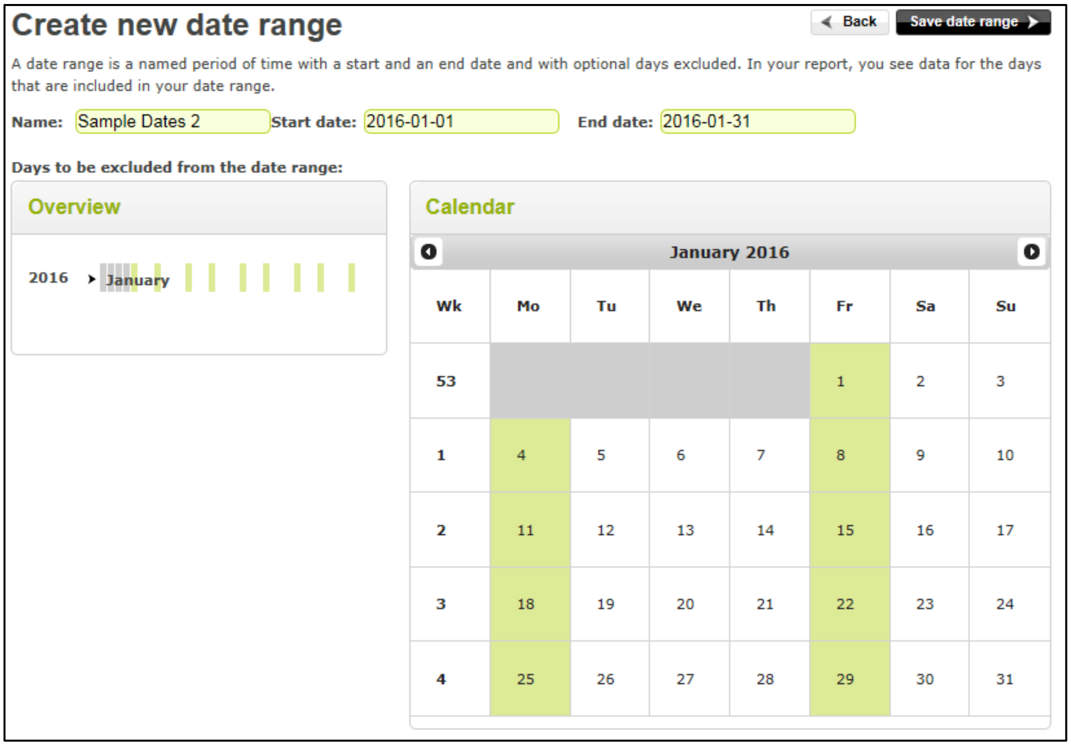


Figure 4. Data Access Screen (Dates) for TomTom Custom Travel Time Tool

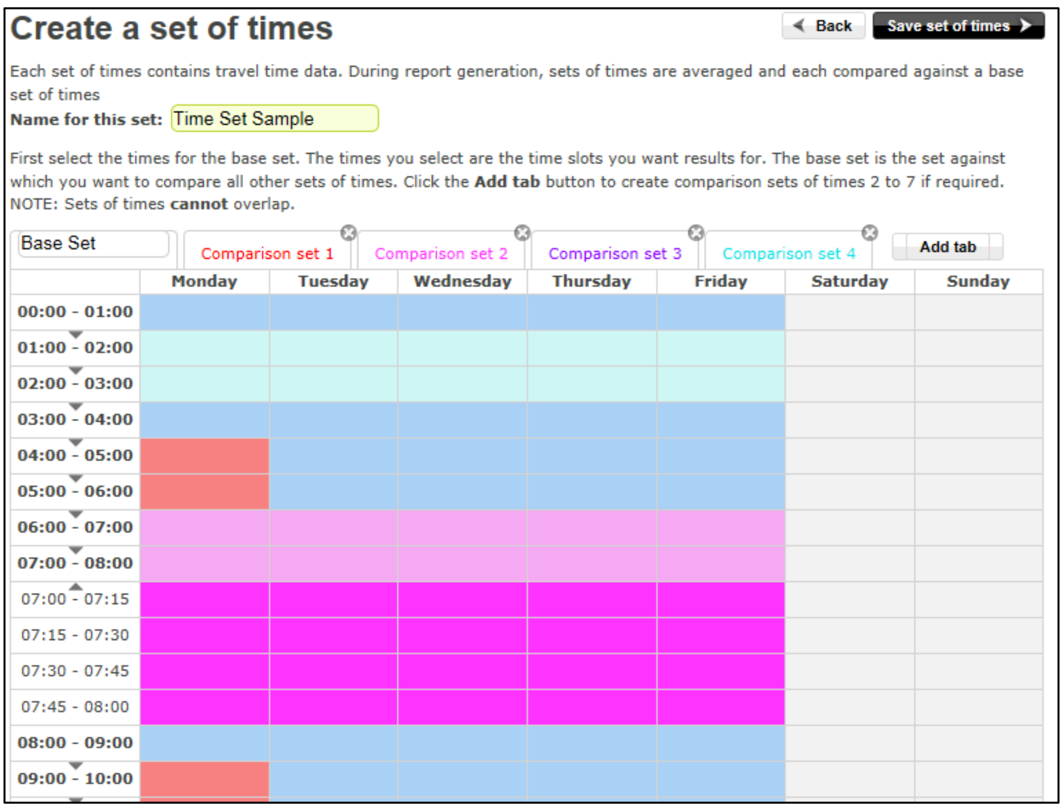


Figure 5. Data Access Screen (Times) for TomTom Custom Travel Time Tool

4.1.3. NPMRDS (National Performance Management Research Data Set)

Access Point: FHWA, https://here.flexnetoperations.com/control/navt/emailnotice
(Data downloaded and then stored in Oracle database)
Access Settings: Route settings, dates, epochs (times)
Interval Size: 5 minutes (epoch)
Dates Available: July 1, 2013, (0:00) - Present
Routes Available: All National Highway System (NHS) routes
Link Type: TMCs
Data Format: Comma Separated Value (static file and travel time data file)
Information Provided: Travel Time
Data Access Screen: See Figure 6

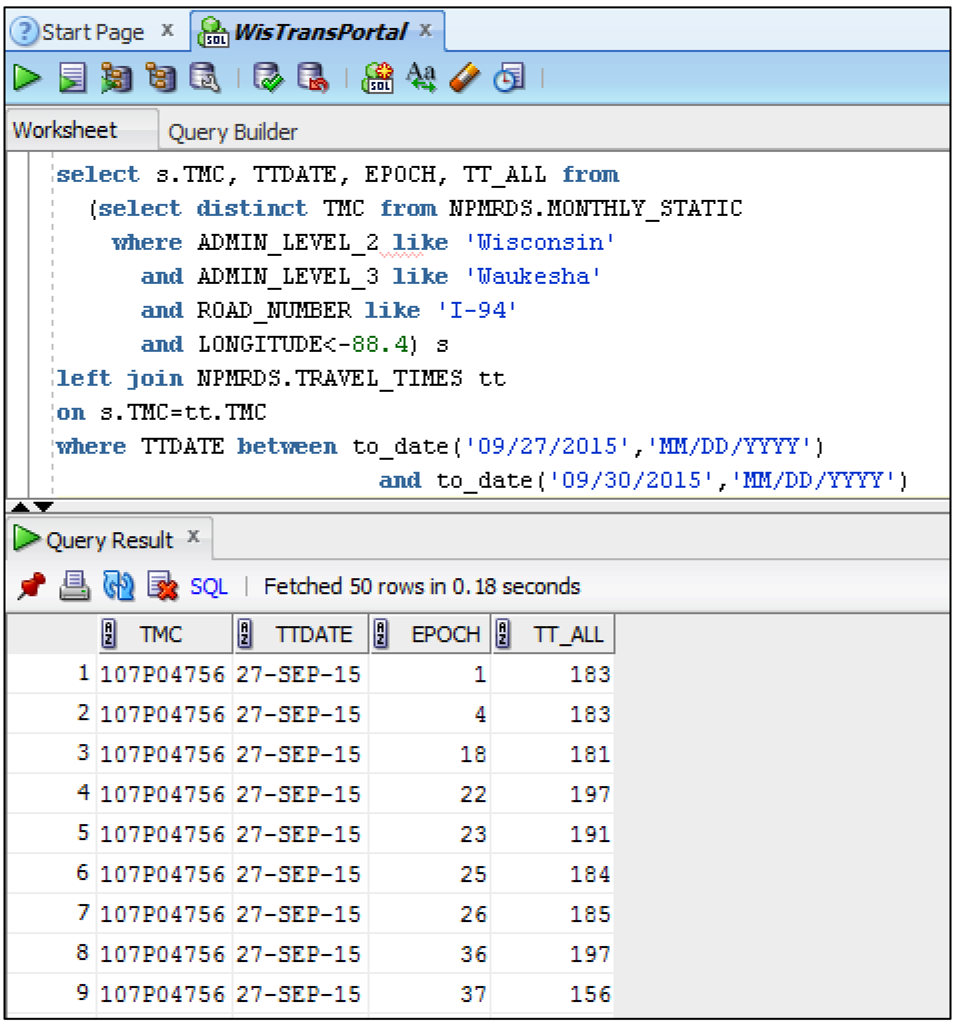


Figure 6. Data Access Screen for NPMRDS (using Oracle SQL Developer)

4.1.4. Bluetooth

Access Point: Drakewell, https://drakewell06.drakewell.com/
Access Settings: Bluetooth units, dates, times
Interval Size: 1 minute
Dates Available: Route Dependent as shown below

Table 4. Bluetooth Data Availability by Route

Corridor	Begin Date	End Date	Bluetooth Units On Route
US 12/18	05/13/2014	Present	WDS-0029, WDS-0030[2], WDS-0031, WDS-0032, WDS-0033[1], WDS-0130, WDS-0034[1], WDS-0035, WDS-0131[2], WDS-0041, WDS-0044, WDS-0046, WDS-0047, WDS-0050, WDS-0051, WDS-0052, WDS-0132[2], WDS-0053, WDS-0133, WDS-0134, WDS-0054, WDS-0028
US 14 M (Madison)	05/16/2014	Present	WDS-0048, WDS-0049, WDS-0078, WDS-0077
US 14 J (Janesville)	10/23/2014	11/02/2015	GL-004, GL-017 (old)[3], GL-014 (old)
E Washington (US 151)	06/10/2016	Present	GL-021, GL-014, GL-025
I-39/90	06/05/2015	Present	GL-005, GL-019, GL-023, WDS-0001, WDS-0136[4], WDS-0135[4], WDS-0002, WDS-0003, WDS-0004, WDS-0005, WDS-0006, WDS-0007, WDS-0008, WDS-0009, WDS-0010, WDS-0012, WDS-0013, WDS-0014, WDS-0016, WDS-0017, WDS-0019, WDS-0020, WDS-0021, WDS-0022, WDS-0023, WDS-0025, WDS-0026, WDS-0027
US 12	11/19/2014	05/04/2015	GL-021 (old), GL-018 (old)[5], GL-001 (old)

[1]Data from these units only available from 11/17/2015
[2]Data from these units only available from 05/22/2016
[3]Data from this unit only available until 04/03/2015
[4]Data from these units only available from 10/22/2015
[5]Data from this unit only available from 04/15/2015

Routes Available: Limited – based on where units are placed
Link Type: Latitude/Longitude Points
Data Format: Excel Spreadsheet
Information Provided: Speed, Travel Time, Match Count
Data Access Screen: See Figure 7

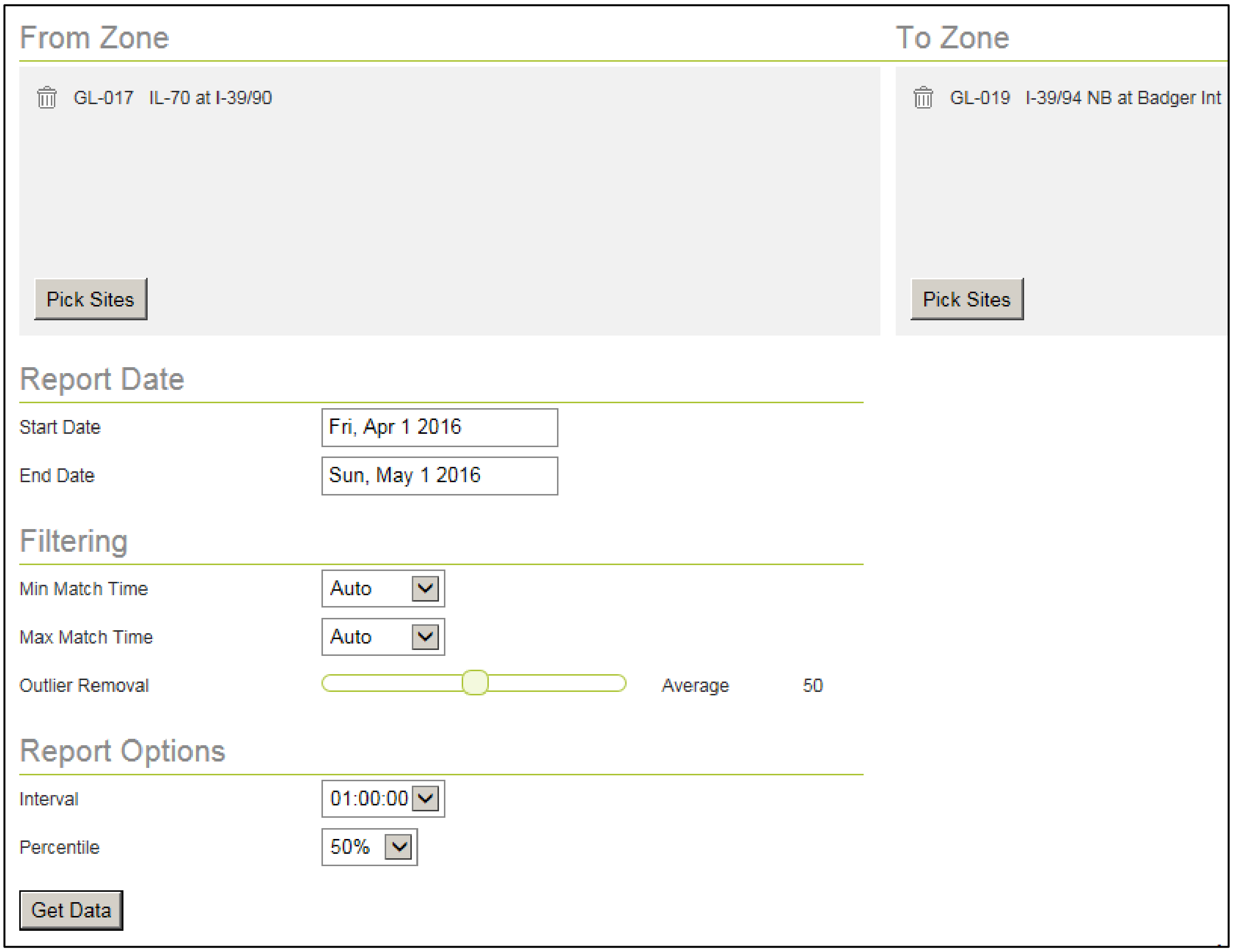


Figure 7. Data Access Screen for Bluetooth Data (using Drakewell Online)

4.1.5. ATR (Automated Traffic Recorder)

Access Point: TOPS Lab TRAffic DAta System (TRADAS),
http://transportal.cee.wisc.edu/products/hourly-traffic-data/
(Data downloaded and then stored in Oracle database)
Access Settings: Traffic site ID, dates, epochs (times)
Interval Size: 60 minutes
Dates Available: January 1, 2014, (0:00) - Present
Routes Available: Limited – based on where units are placed; statewide coverage
Link Type: Latitude/Longitude Points
Data Format: Comma Separated Value
Information Provided: Volume, Speed, Classification
Data Access Screen: See Figure 8

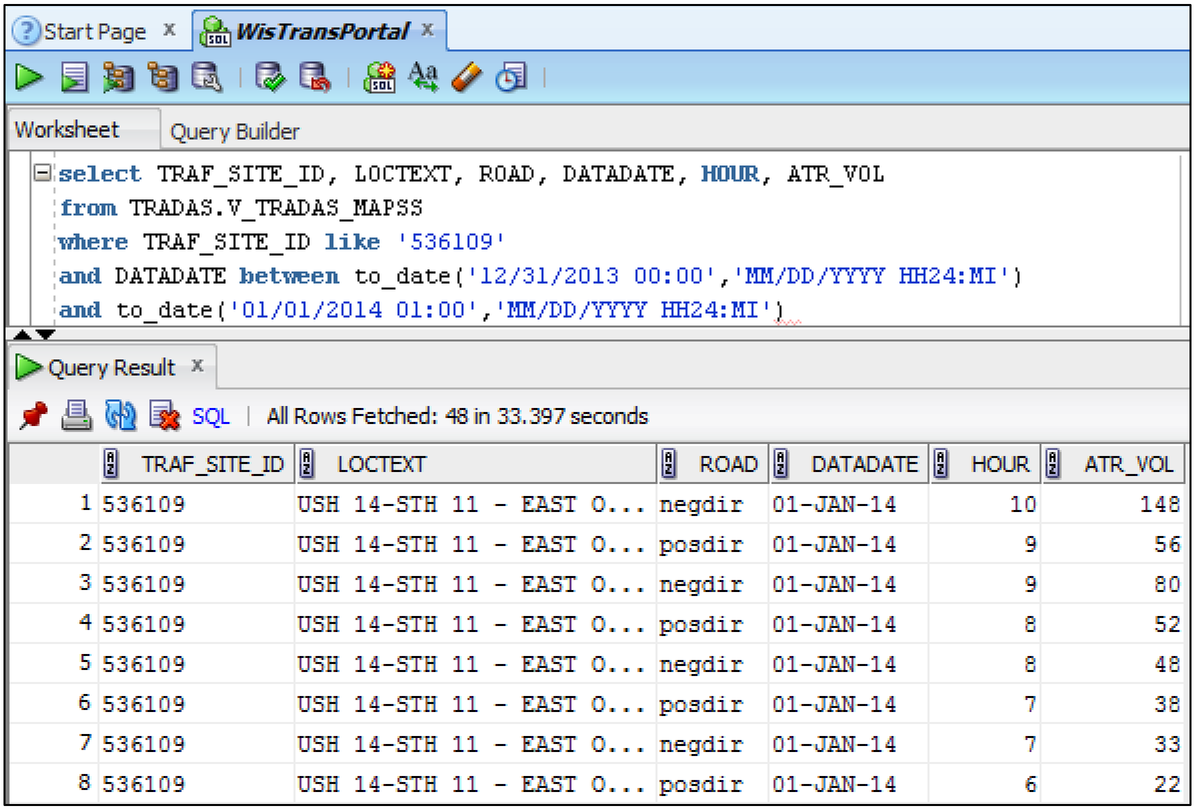


Figure 8. Data Access Screen for ATR Data (using Oracle SQL Developer)

4.1.6. Microwave/Loop

Access Point: TOPS Lab Volume, SPeed, and Occupancy (VSPOC), http://transportal.cee.wisc.edu/applications/V-SPOC/
Access Settings: Controller, Date, Time, Time Interval
Interval Size: 1 minute (or 5 minute)
Dates Available: January 1, 2012, (0:00) – Present for 1-minute data
January 1, 1996, (0:00) – Present for 5-minute data
Routes Available: Limited – based on where units are placed around cities and majority in SE/SW regions
Link Type: Latitude/Longitude Points
Data Format: Comma Separated Value
Information Provided: Volume, Speed, Occupancy
Data Access Screen: See Figures 9 and 10

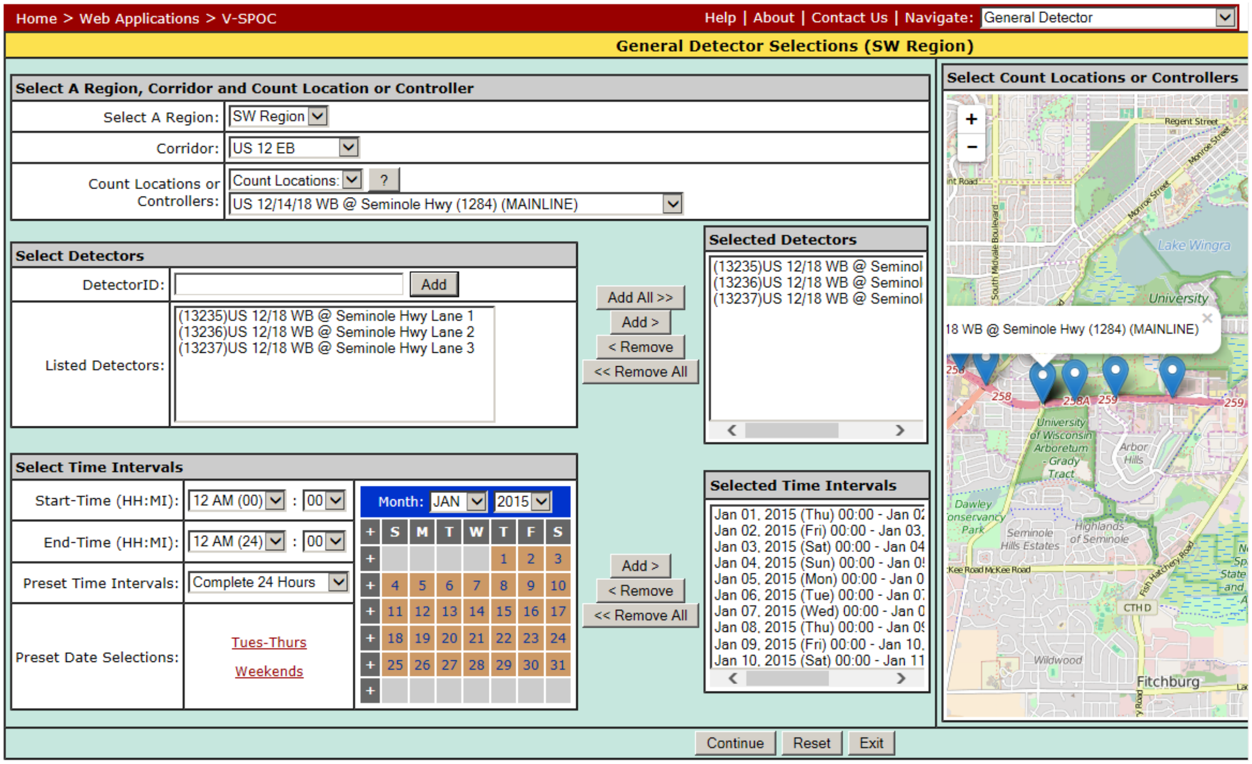


Figure 9. Data Access Screen 1 for Microwave/Loop Data (using V-SPOC online)

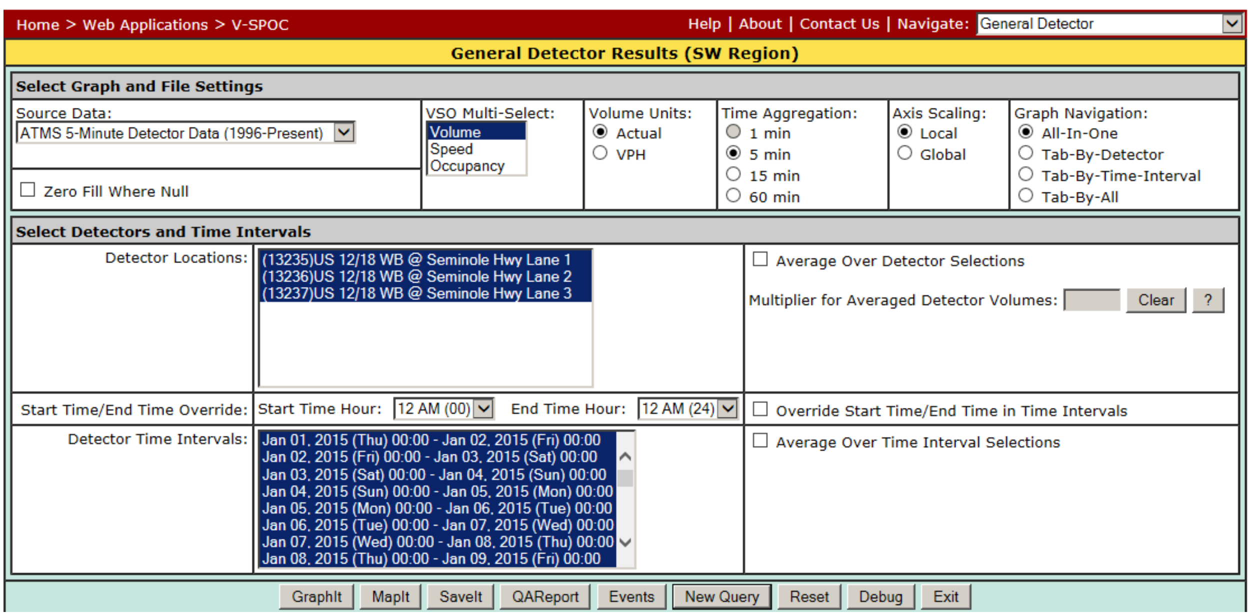


Figure 10. Data Access Screen 2 for Microwave/Loop Data (using V-SPOC online)

4.2. Travel Time Computation

Travel time computation varies by type of data. The computation steps are described briefly below:

4.2.1. TomTom LTA (Live Traffic Archive)

The most difficult data to access is data from the TomTom Live Traffic Archive tool. This data is served in a protocol buffer format from TomTom. Data is accessed using a Protobuf reader and a .proto decoder file. The software used for accessing this data is a modified version of Record Editor (https://sourceforge.net/projects/protobufeditor/) which is a free, open-source software.

Data from the LTA tool is served for the entire state with limited spatial definitions. Therefore, once data is decoded using Record Editor, data must be extracted to a mappable format. Links are represented in OpenLR format which provides the start and end coordinates. This information must be matched to a roadway segments (preferable on the State Trunk Network (STN) used by MetaManager) to create actual highway links. This process is difficult due to varying lengths of segments by route and a disconnect between these segments and the STN and NPMRDS TMC links. Once this is done once, data can be extracted and matched to these links, assuming no changes in the OpenLR codes. If these codes change, the links would have to be reprocessed.

Data is obtained in one-minute intervals and is not filtered for outliers or confidence. Historic data is available for all routes. Full computation steps will be included in the final report as part of the description of Task 3.

4.2.2. TomTom CTT (Custom Travel Times)

TomTom data from the Custom Travel Times tool is much easier to work with than the LTA data, as the output format provided includes an ArcGIS shapefile and an Excel spreadsheet. Excel data can be joined to the routes provided in the shapefile. For reference of this project, the links provided in the shapefile are adequate, however it is preferable to match these segments to the STN.

Data is obtained in 15-minute intervals and is not filtered for outliers or confidence. Historic data is available for all routes. Full computation steps will be included in the final report as part of the description of Task 3.

4.2.3. NPMRDS (National Performance Management Research Data Set)

The National Performance Management Research Data Set is provided as a CSV file which can be joined to the NPMRDS route map which offers segments geo-referenced to traffic message channels (TMCs) and HERE link IDs. Again, for reference of this project, these links are adequate, however it is preferable to match these segments to the STN.

4.2.4. Bluetooth

Bluetooth data is provided from WisDOT owned and GLRTOC owned Bluetooth units. These units are located at various points throughout the state and are referenced by their point coordinates. The software used to access data, C2-Web by Drakewell, allows for routes to be created from multiple Bluetooth points. The software creates routes that match up with Google Maps routes. Like other data sets, these routes are adequate for use in this project, but it is preferable to have these segments matched to the STN for consistency.

4.2.5. ATR (Automated Traffic Recorder)

Automated traffic recorder (ATR) data is available through the TRAffic DAta System (TRADAS). Units are located throughout the state and are referenced by point coordinates. Route creation must be done by matching two or more ATRs along a route and mapping these to the STN.

4.2.6. Microwave/Loop

Microwave and inductive loop data is available through the Volume, SPeed, and Occupancy (VSPOC) data stored on the Wisconsin Transportal. Units are located throughout the state and are referenced by point coordinates. Route creation must be done by matching two or more detectors along a route and mapping these to the STN.

4.3. Statistical Analysis

Once all data is collected and examined, travel times will be compared for all routes and all modes. Based on the literature review, Theil's Inequality Coefficient along with Bias Proportion, Variance Proportion, and Covariance Proportion will be used to compare travel times. These statistics are powerful tools to presents the accuracy and reliability of travel time estimation results across time series. The statistical methods are discussed in detail in the Literature Review.

Analysis will be performed for aggregate data, as well as for specific time intervals

4.4. Data Comparison

A final data comparison will be provided as part of the final report. In addition to comparing travel times for accuracy, data reliability will be measured. For instance, some TomTom links, such as those including heavily traveled interstate highways, include enough observations to make data very reliable. Other links, such as those on two-lane rural arterials, may offer travel times, but only limited observations.

Preferred applications for accessing and processing data will also be compared.

5. Results

5.1. Cost Effectiveness Assessment

A final cost effectiveness assessment will be done to weigh the quality of the travel times and data reliability versus costs of acquiring, maintaining, and processing the data.

5.2. Deliverables

All required tools for processing TomTom archive data from the Live Traffic Archive tool will be included. This includes and algorithms written to process data. The processed TomTom LTA data will also be included for future ease of use. All required tools for processing all other data will also be included along with the processed data.

There will be three written deliverables provided for this project as described below:

5.2.1. Literature Review (Appendix B of this document)

The literature review was completed to both survey previous travel time studies as well as statistical methods used to analyze differences in travel times. Portions of the literature review are included in the analysis plan (with full text in Appendix B of the document). Other parts will be used during the data collection, analysis, and reporting process.

This review included looking at related efforts and past efforts including the 2008 AirSage/INRIX evaluation report and recent GLRTOC work with Bluetooth and probe data including work completed in Janesville comparing Bluetooth, probe data, and NPMRDS data.

5.2.2. Analysis Plan (this document)

The analysis plan (this document) was completed to outline

- the chosen corridors for this study along with dates/times of data comparisons,
- the procedures for accessing and processing the data,
- the statistical methods used to compare travel times and reliability,
- and the procedures for reporting the information.

5.2.3. Final Report

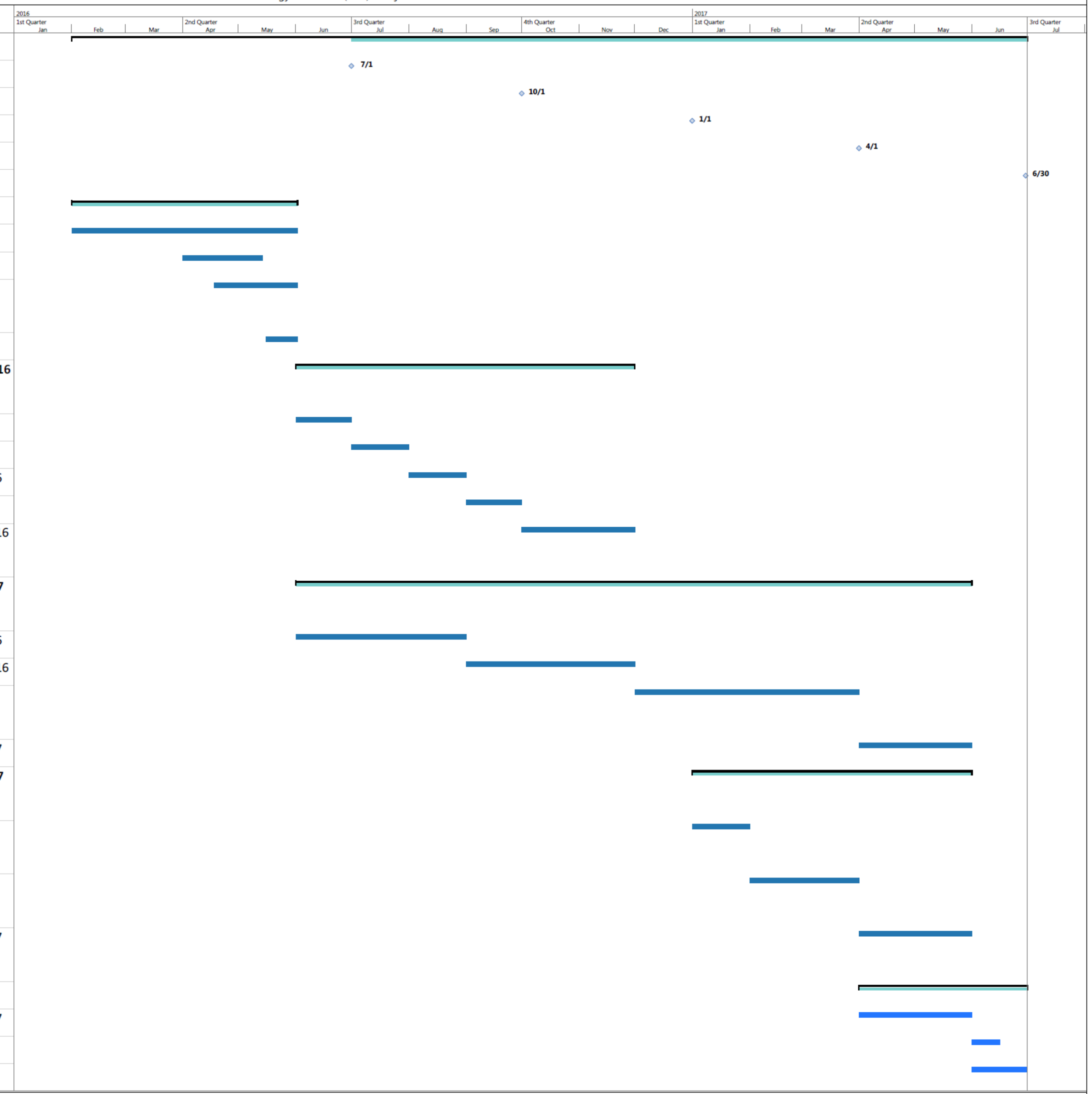
The final report will include all information regarding the process of comparing travel times and reliability. The cost effectiveness assessment will be included to summarize the results and offer recommendations for moving forward.

Once the draft final report is written, a presentation will be delivered to BTO staff and managers. After the presentation, the report will be finalized.

Appendix A. Project Management Timeline

Travel Time Technology Evaluation (T3E) - Project Timeline

ID	Task Mode	Task Name	Duration	Start	Finish
1		**1 Project Management**	**370 days**	**Mon 2/1/16**	**Fri 6/30/17**
2		1.1 Report and Invoice		Fri 7/1/16	
3		1.2 Report and Invoice		Sat 10/1/16	
4		1.3 Report and Invoice		Sun 1/1/17	
5		1.4 Report and Invoice		Sat 4/1/17	
6		1.5 Report and Invoice		Fri 6/30/17	
7		**2 Analysis Plan**	**88 days**	**Mon 2/1/16**	**Wed 6/1/16**
8		2.1 Literature Review	88 days	Mon 2/1/16	Wed 6/1/16
9		2.2 Analysis Plan - Draft	31 days	Fri 4/1/16	Fri 5/13/16
10		2.3 Data Availability Map and Table - Beta	33 days	Mon 4/18/16	Wed 6/1/16
11		2.4 Analysis Plan - Final	13 days	Mon 5/16/16	Wed 6/1/16
12		**3 TomTom Data Development**	**131 days**	**Wed 6/1/16**	**Wed 11/30/16**
13		3.1 Data Access	22 days	Wed 6/1/16	Thu 6/30/16
14		3.2 Data Decoding	22 days	Fri 7/1/16	Sun 7/31/16
15		3.3 Link Decoding	23 days	Mon 8/1/16	Wed 8/31/16
16		3.4 Shapefile Creation	22 days	Thu 9/1/16	Fri 9/30/16
17		3.5 Data Availability Map - Integration	44 days	Sat 10/1/16	Wed 11/30/16
18		**4 Retreiving and Processing Data**	**261 days**	**Wed 6/1/16**	**Wed 5/31/17**
19		4.1 Data Access	66 days	Wed 6/1/16	Wed 8/31/16
20		4.2 Data Processing	65 days	Thu 9/1/16	Wed 11/30/16
21		4.3 Data Availability Map and Table - Final	87 days	Thu 12/1/16	Fri 3/31/17
22		4.4 Summary Statistics	44 days	Sat 4/1/17	Wed 5/31/17
23		**5 Cost Effectiveness Assessment**	**109 days**	**Sun 1/1/17**	**Wed 5/31/17**
24		5.1 Initial and Lifecycle Cost Assessment	23 days	Sun 1/1/17	Tue 1/31/17
25		5.2 Travel Time Effectiveness Assessment	43 days	Wed 2/1/17	Fri 3/31/17
26		5.3 Cost Effectiveness Assessment Summary	44 days	Sat 4/1/17	Wed 5/31/17
27		**6 Report and Presentation**	**66 days**	**Sat 4/1/17**	**Fri 6/30/17**
28		6.1 Draft Report	44 days	Sat 4/1/17	Wed 5/31/17
29		6.2 Final Presentation	11 days	Thu 6/1/17	Thu 6/15/17
30		6.3 Final Report	22 days	Thu 6/1/17	Fri 6/30/17



Project: T3E Project Manageme
Date: Wed 8/17/16

Task	Milestone	Project Summary	Inactive Milestone	Manual Task	Manual Summary Rollup	Start-only	External Tasks	Deadline	Manual Progress
Split	Summary	Inactive Task	Inactive Summary	Duration-only	Manual Summary	Finish-only	External Milestone	Progress	

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Appendix B. Literature Review

Literature review begins on next page

Wisconsin DOT Travel Time Technology Evaluation (T3E)

Literature Review

Zhe Xu, Research Assistant
Jonathan Riehl, Transportation Systems Engineer
Peter Rafferty, TSM&O Program Manager

Wisconsin Traffic Operations and Safety (TOPS) Laboratory
University of Wisconsin–Madison
Department of Civil and Environmental Engineering

September 2016

Project Title: Travel Time Technology Evaluation (T3E)
Project ID Number: 0072-40-53
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Work Order Number: 9.30
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Funding Appropriation: 365 – Highway system management and operations

Table of Contents

1. Introduction of Travel Time Estimation

Travel time is an important transportation metric. It is often directly conveyed to users through the use of dynamic message signs (DMS), 511 traveler information systems, and other avenues to allow individuals to make choices about their routes. Commonly used travel time data collection methods include the use of inductive loops, radar, video cameras, and probe vehicles. Travel speed is usually measured at a point by radar or loop detector, or in the case of probe-based identification and Bluetooth detection, through the travel distance divided by travel time.

Recently, some data quality assessments of probe-based travel time and travel speed estimation technologies have been conducted. Research groups from various universities participated in evaluation cases, while third party consultants conducted other cases. The motivation of these studies was to measure the accuracy of speeds and travel times obtained from travel time data service providers. Ground truth travel time data from multi-source probes was collected and compared to evaluate the accuracy of the data. Performance metrics such as mean absolute error (MAE), error bias, or root mean squared error (RMSE) was used as indicators of data accuracy[i]. However, to measure an estimate's error, it is important to agree on how to obtain the ground truth data. There are significant differences in the methods used to collect ground truth data and in the statistical methods used to measure accuracy.

This literature review report summarizes the commonly used travel time data collection methods as well as the accuracy measurement methods. The advantages and shortages of the methods are analyzed. The report also provides an overview of past efforts to measure the accuracy of travel time estimation technologies.

2. Travel Time Estimation and Data Collection Technologies

2.1. Point Sensors

A point sensor measures the presence and speed of vehicles that travel by the location point where the sensor device is deployed.

2.1.1. Loop Detectors[ii]

<u>*Half-Distance Approach*</u>

In this approach, the assumption is that the speeds measured by a set of dual loop detectors are valid to half-distance on both sides. Therefore, the travel time between the two loops is defined as follows:

$$T_{a-b} = \frac{1}{2}(\frac{D}{V_a} + \frac{D}{V_b})$$

where V_a and V_b are the average speed measured at loop A and B respectively, for a specific time interval,
T_{a-b} is the travel time between loop A and loop B,
and D is the distance separating the two loops.

Average Speed Approach

In this approach, the average speed is the average of the two speeds measured by the two loops:

$$T_{a-b} = \frac{D}{(V_a + V_b)/2}$$

where V_a and V_b are the average speed measured at loop A and B respectively, for a specific time interval,
T_{a-b} is the travel time between loop A and loop B,
and D is the distance separating the two loops.

Minimum Speed Approach

The minimum speed detected by the loops will be assumed to be the speed of the vehicle during his travel between the two loops:

$$T_{a-b} = \frac{D}{V_{min}}$$

where V_{min} is the minimum speed measured by loop A and B,
T_{a-b} is the travel time between loop A and loop B,
and D is the distance separating the two loops.

2.2. Probe Data Systems[iii]

2.2.1. Video and License Plate Readers

Travel time can be measured by automatic plate recognition systems (APRs). The measurement requires at least two fixed APR systems on the road. When a vehicle passes by the first APR system, the video recorder of the APR will read its plate number. Then when the same vehicle passes through the second APR system, its plate number will be recorded again. Finally, the server will match the plate numbers and their time stamp tags. By matching the time stamp and measuring the distances between the set of APR systems, the travel time and travel speed of the vehicles could be measured.

2.2.2. Radar

Radar detectors can collect velocity, flows, and occupancy data when they are deployed along the roadside. Since the radar detection is strongly impacted by the road environment, radar is more widely implemented on rural highways rather than in urban areas. Although radar is suitable with massive data collection, the collected data has low accuracy.

Radar uses vehicle speed, S, computed using the time difference, ΔT, corresponding to the vehicle reaching at the leading edges of two range bins.

The distance D separating the range bins is known. The vehicle speed is given by:

$$S = \frac{D}{\Delta T}$$

where D is the distance between leading edges of the two range bins,
and ΔT time difference corresponding to the vehicles arrival at the leading edge of each range bin.

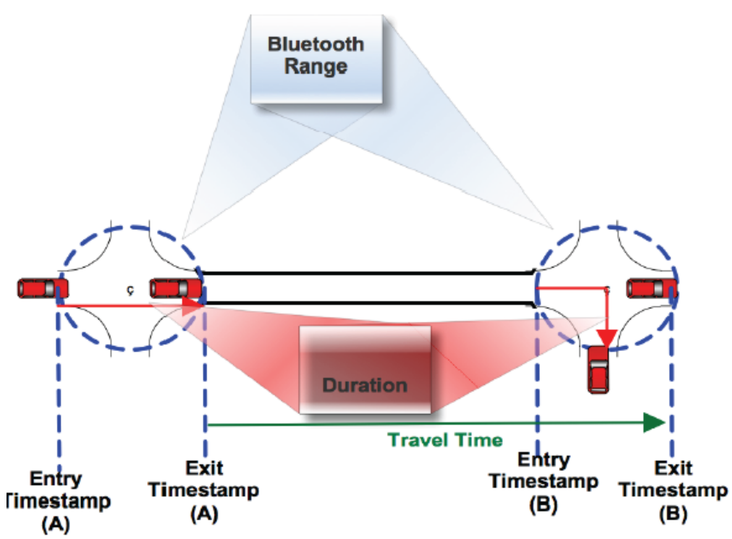
2.2.3. Bluetooth

Bluetooth detectors scan the area range and check if any Bluetooth enabled device are detected. Once the vehicle equipped with Bluetooth devices drive into the detection range of a Bluetooth reader, enter and exit time stamps of the devices are recorded. Therefore, travel time and travel speed can be determined between points on the roadway.

The Bluetooth data gives a straight measurement of travel time between pairs of scanners. The data includes the "duration" of time required for the vehicle to pass the range detection limits of the Bluetooth scanner. Thus, Bluetooth data can give the entry and exit timestamp for each of the detectors which provides the duration of each Bluetooth device. The travel time is given by the following equation:

$$Travel\ Time = ET_b - ET_a + D_b$$

where ET_b is the entry timestamp at Bluetooth detector B,
ET_a is the entry timestamp at Bluetooth detector A,
and D_b is the duration at Bluetooth detector B.



2.2.4. Wifi Technology

Wifi Technology could be used to measure the travel time of vehicles when the location of the probe vehicle and its distance to the next WiFi spot is known. However, the measurement is affected by the noise impacting the localization of the car. Therefore, this technology is accurate enough for route planning, but it does not work well for individual road section estimation.

2.2.5. High-Frequency GPS Data

High-frequency GPS is a method where the probe vehicle can send GPS information every few second or each second (no more than 10 seconds). This aspect makes the data the most accurate for travel time estimation. However, the number of GPS enabled probes may limit its application. There are also some map matching problems for the complex environment such as roundabouts or intersections. This is the general strategy used by providers such as TomTom, Inrix, and HERE; although they do use a variety of other probe data sources.

2.3. Summary

Studies have reported that point sensors (such as loop detectors) have been found to be unreliable for travel time estimation since they only capture time mean speed instead of space mean speed. Thus, some errors may exist. The accuracy of travel time estimated from point sensor data tends to decrease as congestion levels increase.

Wisconsin currently employs point sensors in their travel time estimations through the use of volume, speed, and occupancy (V-SPOC) data derived through point detection in collaboration with vehicle detection communication statistics in the Advanced Traffic Management System (ATMS).[iv] This method has shown to be more robust than what has been shown in other studies using pure point detector data.

On the other hand, probe data such as floating car data (GPS, Wifi, Bluetooth) and AVI Data (APR and Toll Tag Readers) provide the potential for more accurate travel time than point sensors. GPS has the high accuracy despite its probe penetration rate limitation, while the other technologies require the deployment of multi-sensors. As part of this study, point detectors will be compared with probe technologies.

3. Travel Time Estimation/Prediction Models

3.1. Statistical Approach Measuring Error[v]

Mean Absolute Error (MAE)

MAE gives a measure of the average magnitude of error between two data sets (i.e., a service provider's data and ground truth travel times). However, the MAE does not indicate whether the estimates tend to be over-estimates or under-estimates. The MAE is defined as:

$$\mathrm{MAE} = \frac{1}{\mathrm{t}}\sum_{\mathrm{i}=1}^{\mathrm{t}} \mathrm{abs}(\mathrm{Travel\ Time}_{\mathrm{i}}^{\mathrm{A}} - \mathrm{Travel\ Time}_{\mathrm{i}}^{\mathrm{B}})$$

Root Mean Square Error (RMSE)

RMSE can help identify where a service provider has many accurate estimates but also has a few estimates that are particularly far off from the ground truth. It identifies these cases by squaring the errors first, taking an average of the squared errors, and finally taking the square root of the average to report the metric in the base units. Because squaring is a non-linear operation it weights outlier observations more heavily and gives a better indication of whether a data set contains outlier observations. The RMSE is defined as:

$$\mathrm{RMSE} = \sqrt{\frac{1}{T}\sum_{i=1}^{t} (\mathrm{Travel\ Time}_{\mathrm{t}}^{\mathrm{A}} - \mathrm{Travel\ Time}_{\mathrm{t}}^{\mathrm{B}})^2}$$

Correlation Coefficient, ρ

Correlation Coefficient, $\boldsymbol{\rho}$, is the quantitative measure of correlation between datasets. $\boldsymbol{\rho} = 1$ is total positive correlation, 0 is no correlation, and -1 is total negative correlation.

$$\boldsymbol{\rho} = (\frac{1}{\sigma_A * \sigma_B * T}) \sum (Travel\ Time_t^A - \overline{Travel\ Time_t^A})(Travel\ Time_t^B - \overline{Travel\ Time_t^B})$$

Theil's Inequality Coefficient, U – Travel Time Difference

Theil's inequality coefficient is used to analyze the difference between two travel times. The value of U will fall between 0 and 1. If U = 0, all travel times are equal and there is a perfect fit. If U=1, the predictive performance of the model is unreliable.

$$U = \frac{\sqrt{\frac{1}{T}\sum_{i=1}^{T}(Travel\ Time_t^A - Travel\ Time_t^B)^2}}{\sqrt{\frac{1}{T}\sum_{i=1}^{T}(Travel\ Time_t^A)^2} + \sqrt{\frac{1}{T}\sum_{i=1}^{T}(Travel\ Time_t^B)^2}}$$

Bias Proportion, U^M – Bias of U

Bias proportion, U^M, is an indication of systematic error and it measures the extent to which the average values of the two travel time series deviate from each other. Whatever the value of the inequality coefficient U, it is best for U^M to be close to zero. A large value of U^M would mean that a systematic bias is present.

$$U^M = \frac{(\overline{Travel\ Time_t^A} - \overline{Travel\ Time_t^B})^2}{(\frac{1}{T})\sum(Travel\ Time_t^A - Travel\ Time_t^B)^2}$$

Variance Proportion, U^s

The variance proportion, U^s, indicates the ability of the travel time estimation to replicate the degree of variability in the variable of interest. If U^s is large, it means that one of the series has fluctuated considerably while the other series shows little fluctuation.

$$U^s = \frac{(\sigma_A - \sigma_B)^2}{(\frac{1}{T})\sum(Travel\ Time_t^A - Travel\ Time_t^B)^2}$$

Covariance Proportion, U^c

The covariance proportion, $U^{\mathbf{c}}$, measures unsystematic error. It represents the remaining error after deviations from average values have been accounted for. Since it is unreasonable to expect predictions to be perfectly correlated with actual outcomes, this component of error is less worrisome than the previous two. The ideal distribution of inequality over the three sources is $U^M = U^s = 0$ and $U^c = 1$.

$$U^c = \frac{2(1 - \boldsymbol{\rho})\sigma_A\sigma_B}{(\frac{1}{T})\sum(Travel\ Time_t^A - Travel\ Time_t^B)^2}$$

3.2. Artificial Intelligence Approach[vi]

One of the most popular Artificial Intelligence techniques is the neural network (NN). The neural network has been explored in many prediction and estimation fields. Some researchers develop travel time prediction models using the artificial neural network with cluster method. The algorithm is based on the functional relationship between real-time traffic data (input) and actual travel time data (output). The clustering method is used in the algorithm to reduce the data features with less input while preserve the original traffic physiognomies. Then travel time forecasting is obtained by inserting the real-time traffic data into the functional relation.

However, the neural network approach requires much more input information than other methods. Thus, the algorithm, if done well, could improve the quality of the predictions or the results. However, this process is complicated for calculation and calibration, which is not efficient for large travel time data comparison.

To conclude, the Artificial Intelligence Approach is a powerful tool but needs more adjustments and calculations to obtain an accurate estimation. Therefore, it's not the ideal method for travel time comparison when the data set is large.

3.3. Summary

Theil's Inequality Coefficient along with Bias Proportion, Variance Proportion, and Covariance Proportion provide a useful method for measuring the error variance. What's more, these simulate the model by presenting the error and its variation over time. Thus, it is a powerful tool to present the accuracy and reliability of travel time estimation results across time series.

The Artificial Intelligence Approach is helpful in travel time estimation. However, the computation process is complicated and time-consuming. It is not efficient for travel time comparison when the data set is large.

4. Federal Rule 1201 23 CFR 511 - Travel Time Requirements

4.1. Wisconsin

The minimum accuracy and maximum latency of travel times calculated and then disseminated by WisDOT is governed by "United States Department of Transportation (USDOT) Federal Rules and Regulations". WisDOT is required to provide traveler information that is accurate per Title 23 CFR Part 511 which mandates travel time accuracy to within 85% of the actual travel time delivered to the traveling public within 10 minutes of the initial speed measurement with an overall travel time availability of 90 percent. Ensuring that the displayed travel times are correct provides drivers with confidence that the information is indeed accurate and reliable. Travel time information can also be used to assess the overall performance of the transportation network. Travel time verification provides a means to perform quality control and quality assurance on this important data source.[vii]

4.2. Washington

The Washington DOT (WSDOT) tracks mobility performance data for 35 important commutes in the Central Puget Sound region and two commutes in Spokane. WSDOT reports average travel time, 95% reliable travel time, traffic volume (polled every 20 sec, aggregated to 5 minutes), the duration of peak period congestion, and the percent of weekdays when average travel speeds fall below 35 mph. These routes are tracked for changes in traffic conditions on a yearly basis.

4.3. Minnesota

The Minnesota Department of Transportation (MnDOT) conducted a travel time data comparison between commercial probe data (INRIX data) and MnDOT data. A parameter discussed with the Project Team is that freeway travel time reports within 10%, or 2 minutes of the MnDOT value should be considered very accurate and suitable for disseminating to the traveling public. For arterial roads, the Project Team developed requirements for this project to report arterial travel times within a 12% difference from vehicle travel time run data. The evaluation team has used this 12% value; however, they suggest that vehicle travel time runs on arterials are less precise than vehicle travel time runs on freeways.

4.4. California[viii]

The California Department of Transportation (Caltrans) prepared the 2014 Real-Time System Management Information Program (RTSMIP) compliance report to demonstrate conformance with the provisions of accurate and available traffic and travel conditions reporting statewide on interstate highways by federal regulations. For construction activities and travel time information, the regulations define metropolitan areas as geographical areas designated as Metropolitan Statistical Areas (MSAs) with a population exceeding one million inhabitants. Compliance with federal regulations in reference to the four provisions is measured by the accuracy and availability of the reported information. The accuracy of information measurement is 85 percent accurate at a minimum, or a maximum error rate of 15 percent and the availability of information measurement is 90 percent available at a minimum.

4.5. Florida

The Florida Department of Transportation (FDOT) District 4 established a traffic data collection system in which volume, occupancy, and speed data is obtained from sensors spaced every 0.5 mile within two freeway corridors. Travel times are then reported in 15 minute intervals for 40 miles of interstate freeways spanning I-95 and I-595 near Miami. Traffic flow performance measures will be reported automatically on the SunGuide website along with their existing incident management performance reports.[ix]

4.6. Virginia

The pilot test data submitted from the Virginia Department of Transportation (VDOT) rises from two separate data collection systems. The primary data used for statewide monitoring comes from 216 continuous count stations distributed throughout the state that are polled every 15 minutes. This data is used to report speed and various throughput measures. A speed index performance measure developed by the University of Virginia is compiled using data from the continuous count stations. The speed index is used in conjunction with throughput data as aggregate measures of system performance. The second data collection system reported is a network of fixed sensors on I-66 in Northern Virginia. This system is used to assess speed, travel time, and extent of congestion measures in that corridor.

5. Similar Projects and Major Findings

There are five major data service providers that estimate travel times from cellular phone data and other sources. These providers are Airsage, Cellint, HERE, Inrix, and TomTom. Both Airsage and Cellint are data service providers that estimate travel times from cellular phone data.

HERE, Inrix, and TomTom estimate travel times from a fusion of commercial GPS data, DOT sensor data, and other proprietary data sources. HERE has publically released their data for the National Highway System (NHS) as the National Performance Management Research Data Set (NPMRDS).

Three of these providers (Airsage, Cellint, and Inrix) have been evaluated in the United States. In addition to evaluations of these three vendors, there have been a number of other efforts to develop and/or evaluate travel time data technologies. For example, the Mobile Millennium project at the University of California, Berkeley focused on evaluating the use of SmartPhone technology to estimate travel times. Research at the University of Akron focused on an evaluation of data posted on variable message signs and NAVTEQ conducts an ongoing audit of traveler information in a number of different markets.

The results of these evaluations have been mixed. The evaluation of Inrix by the University of Maryland and the I-95 corridor coalition has been extensive and the results are publicly available through the website (see below). One of the important aspects of this evaluation is the use of Bluetooth data readers for measuring ground truth travel times. Most of the other evaluations have used either floating car or loop detector measurements as ground truth. This is understandable given the relatively recent development of Bluetooth reader technology. However, it is possible that future evaluations will use a mix of AVI and floating car data for evaluations. Table 1 shows a summary of various studies of these service providors.

The Minnesota Department of Transportation (MnDOT) conducted a travel time data comparison between commercial probe data (INRIX data) and MnDOT data. The results found that for the urban freeway test location, 98% of the comparisons of INRIX travel time data were either within 2 minutes or 20% of the MnDOT travel times; for the urban arterial test location, 98% of the comparisons of INRIX travel time data were within 5 minutes of the vehicle travel time run data.[x] The analysis also indicated that the INRIX data is more accurate when travel speeds are near posted speeds.

The University of Washington conducted a study to provide decision support for transportation agencies to select travel time systems based on the accuracy, reliability, and cost. The sensor systems tested were Washington State Department of Transportation's pre-existing automatic license plate reader (ALPR) system, Sensys emplacements, the TrafficCast BlueTOAD system, Blip Systems BlipTrack sensors, and a third-party feed from Inrix. This study's approach was to look at the Mean Absolute Deviation (MAD) to judge the expected magnitude of error, then examine the Mean Percent Error (MPE) to find any systematic biases in the data.[xi]

Louisiana conducted a study to investigate the feasibility of using a Bluetooth Probe Detection System (BPDS) to estimate travel time in an urban area. Specifically, the study investigated the possibility of measuring overall congestion, the trend in congestion, the location of congestion "hotspots," and the measurement of the level of congestion at the hotspots using a BPDS. The findings of the study indicate that a BPDS can reliably be used to measure travel time and estimate congestion regarding indices such as travel delay, planning time index, and travel time index.[xii]

The Wisconsin Traffic Operations and Safety (TOPS) Lab conducted a travel speed estimation comparison between the Bluetooth data and National Performance Management Research Data Set (NPMRDS) data in Janesville, Wisconsin. Theil's inequality coefficient was used for measuring the Bluetooth estimation performance. Comparison results show the high accuracy of Bluetooth data although the probe penetration rate is as low as 6%. Also important to note, the Bluetooth data set indicated the speed drop off phenomenon caused by a traffic incident, which shows the reliability of the Bluetooth data in Janesville Study.[xiii]

Table 1. Summary of Probe Data Service Provider Studies

Service Provider	Evaluator	Time Frame	Ground Truth Data	Error Metric	Results
Inrix	University of Maryland	Ongoing since 2008	Bluetooth (with floating car validation)	MAE, Speed Error Bias	Study shows that speed estimates are <10 mph error
AirSage	University of Virginia	2005	Floating car data and loop detectors	MAE, Speed Error Bias	68% of speed estimates had greater than 20 mph error
AirSage	GeoStats	2008	Floating car data	% of times of congestion detected	Three markets tested, found >85% of time congestion correctly detected
Cellint	URS, GeoStats, Georgia DOT	2007	Floating car and calibrated loop detector model	Paired t-test of means	Significant match in speeds between 20 and 70 mph. Below 20 mph did not perform well
Mobile Millennium Project	University of California	2008	Loop detectors	Absolute percent error	Less than 5% penetration rate of probes could provide accurate estimates of speeds.
GLRTOC	Wisconsin TOPS Lab	2015	National Performance Management Research Data Set (NPMRDS)	Theil's inequality coefficient	High accuracy of Bluetooth data although the probe penetration rate is low as 6%

6. Conclusion – What to Take Away from Previous Projects

This project intends to compare the travel time technologies and understand the quality of probe data and appropriate use applications. Based on the experience of the previous similar projects, the literature review study concludes the following study plan.

6.1. Travel Time Data Collection Methods:

Point Sensors (such as loop detectors) are not directly suitable for travel time estimation because the accuracy of travel time estimated from point sensor data tends to decrease as congestion levels increase. It may work well for validating ground truth measurements from other data sources, but should not be used as the sole source of ground truth data for assessments of travel time data. Probe data such as floating car data (e.g., GPS, Wifi, and Bluetooth) and AVI Data (e.g., APR and Toll Tag Readers) may provide more accurate travel time than point sensors. GPS has high accuracy despite its probe penetration rate limitation, while other technologies require the deployment of multi-sensors.

The findings in the literature review will be used as a base for data sources and statistical analysis methods in the analysis plan. The analysis plan will compare current technologies in use by WisDOT, including loop detectors, microwave sensors, and automatic traffic recorders (ATRs) to emerging technologies such as Bluetooth and the NPMRDS. WisDOT is also working with a trial of TomTom data tools that will be incorporated into the project.

6.2. Estimation/Prediction Methods

Statistics and metrics are chosen based on the experience of previous related projects and the adaptation of WisDOT travel time quality assurance, quality control (QAQC) process. Theil's Inequality Coefficient along with Bias Proportion, Variance Proportion, and Covariance Proportion provides a useful method for measuring the error variance between two datasets. Additionally, these simulate the model by presenting the error and its variation over time. Thus, Theil's statistics are a powerful tool to presents the accuracy and reliability of travel time estimation results across time series. Thus, Theil's statistics as well as summary statistics will be used to compare travel times across the sources being analyzed.

Although the Artificial Intelligence Approach is helpful in travel time prediction, the computation process is complicated and time-consuming. It is not efficient for travel time comparison when the data set is large. Thus, this method could be used for travel time prediction if input data is sufficient, but it is hard to implement for travel time comparison and analysis and will therefore not be used in this project.

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