Wisconsin DOT Travel Time Technology Evaluation (T3E)

TRAVEL TIME TECHNOLOGY EVALUATION

Final Report

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

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

August 2017

Project Title: Travel Time Technology Evaluation (T3E)
Project ID Number: 0072-40-53
Master Contract Number: 0072-39-25
TOPS Lab Work Order Number: 9.30

Table of Contents

List of Figures

List of Tables

Executive Summary

This project evaluated third party GPS probe data purchased for real-time travel times versus competing technologies including Bluetooth detectors, microwave radar, and inductive loops. The National Performance Management Research Data Set (NPMRDS) is also used to compare quality of travel times.

WisDOT currently offers travel times to road users in a variety of ways including through dynamic message signs (DMS), the Wisconsin 511 system, and the XML feed. These times need to be accurate and relevant.

In order to judge the quality of travel times provided, historic travel times are considered in this comparison study. Various routes across Dane and Rock counties are utilized such that not just freeways are being studied. The different functional classes include eight routes, a mix of urban and rural freeways and arterials. There are also seven time periods studied including rush and peak hours, as well as daytime, weekends, and nighttime.

For this comparison, an overall cost-benefit analysis is performed as outlined in this report. Many costs are included to show the true cost of using data, including costs for acquisition of data (hardware, software, procurement, administrative, etc.), maintaining data, processing data, and integrating data into the current system. Benefits are measured by looking at data quality in a number of ways including reliability, accuracy, availability, latency, consistency, missing data, incorrect data, sampling rates, and vehicle re-identification.

For limited deployments (e.g., for a construction project along a single segment of a route), all detection types have a similar cost, and selection of travel time technology would depend on current availability of technologies (e.g., are 3rd party data already purchased, are there Bluetooth detectors on hand that could be installed quickly, etc.). Although expanded deployments result in decreased unit costs for all detection types, 3rd party probe data see an even more significant cost savings as deployment scope widens. Thus for a statewide deployment, such as for the entire National Highway System (NHS) routes in the state, 3rd party probe data is the most cost-effective deployment.

In terms of benefits, all travel time technologies have their pros and cons when it comes to reliability and availability, as outlined in this report. Although technologies such as Bluetooth and TomTom tend to have low vehicle capture rates as compared to traditional microwave and loop detection, this does not appear to affect the quality of speeds and travel times reported. This is true across most functional classes of facilities and all time periods in this study. Statistical comparisons are performed on speeds and travel times across all technologies showing this more clearly, and showing special cases where a certain technology might be a bit better than another.

As expected, there is not one catch-all recommendation for which technology to use. Recommendations depend on scope of deployment, available resources, functional class of the facility as well as the specific facility, and so on. These recommendations are included in this report.

1. Project Introduction and Background

A primary motivation for the T3E project was to understand the quality of GPS-based probe data and appropriate use applications. Specifically, this project focuses on the evaluation of third party GPS probe data purchased for real-time travel times in Dane and Rock counties and its appropriate use applications. In conjunction with the I-39/90 expansion and Verona Road construction projects, a real-time TomTom data feed has been purchased by WisDOT with expansion and renewal options up to seven years covering Rock and Dane counties. This evaluation compares 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.

Data accuracy, availability, and latency are assessed to determine further applications of this data source. Evaluation includes purchased TomTom GPS-based probe data, the free FHWA National Performance Management Research Data Set (NPMRDS), Bluetooth detection maintained by WisDOT or the Great Lakes Regional Transportation Operations Coalition (GLRTOC), microwave detection, inductive loops, and other Automatic Traffic Recorders (ATRs). Data from these sources are currently available to WisDOT and the TOPS Lab, and are being used for various applications. This evaluation project follows on previous evaluations of selected detection technologies and aligns with WisDOT's Transportation Systems Management and Operations Traffic Infrastructure Process (TSMO-TIP).[1]

This evaluation identifies the quality of travel time data sources, where quality indicators include availability, accuracy, latency, and other factors, for further application to provide travel times on both freeways as well as primary arterial roads (interrupted flow facilities). Probe data have known deficiencies, including poor availability during low volume or stopped traffic conditions. The existing TomTom probe data contract has optional renewal periods. Identifying the quality and shortcomings of the data allows WisDOT to determine expansion and use applications.

Statistics and metrics were 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 floating car travel time runs.

Project documents and online tools are available on the TOPS T3E website.[2]

1.1. Reasons for Evaluating Technologies

WisDOT recognizes the value and economic benefits of traveler information. This includes providing information via 511 and other means on closures, incidents, hazardous road conditions, and of course travel times and delays. 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 confidence in the system. In situations where delays are expected,

[1] More information about the TSMO-TIP is available via http://www.topslab.wisc.edu/tsmo/tip/
[2] The T3E website address is http://www.topslab.wisc.edu/tsmo/t3e

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.

Real-time travel times are already available via smartphones and navigation aids, and with the onset of connected vehicles, travel time information will be 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 among competing technologies,
- compare difficulty of accessing and processing data sources,
- determine other uses of travel time data, and
- integrate technologies into the transportation systems management and operations (TSM&O) decision process for detection.

Results of this evaluation include an overall cost-benefit comparison in the conclusion section which is based upon analysis completed for the project, which is comprised of the following parts:

- Data quality including access, latency, reliability, and durability of equipment (Section 2)
- Data availability including acquisition of data (Section 3)
- Travel times including travel speeds and statistical analyses comparing routes (Section 4)
- Cost effectiveness assessment (Section 5)

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.

1.2. Existing Travel Times

WisDOT travel time information is currently calculated based on speed or timestamped location data collected by a variety of traffic data detection devices located along a road corridor that is then integrated into the ATMS software used by WisDOT. This includes probe data collected on selected routes.

WisDOT has been using speed data from in-pavement inductive wire loops and microwave detection devices to calculate travel times for decades. 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 Statewide Traffic Operations Center (STOC) were then integrated into WisDOT's ATMS software around the same time and can now be used as another data source for travel time calculation. Third party probe data are purchased and provide travel time data in the Southwest Region. WisDOT considers this source when new travel time routes are needed.

1.3. 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 (ATRs, microwave detectors, and loop detectors) as well as other emerging data sources (Bluetooth detectors and the National Performance Management Research Data Set (NPMRDS)).

Table 1.1 summarizes the technologies to be analyzed for this project along with their availability. In the following subsections, each technology is discussed briefly.

Table 1.1. Travel Time Technologies used in the Study

Technology	Time Interval (min)	Availability Period	Data Format
TomTom (CTT)	15	Jan. 1, 2008, 0:00 – Present	KML, XLS, SHP
TomTom (LTA)	1	Apr. 14, 2015, 8:00 – Present	ProtoBuf (OpenLR)
Bluetooth	1	Varies by site[3]	XLS
NPMRDS	5	Jul. 1, 2013, 0:00 – Present	Database (CSV)
Microwave	1	Jan. 1, 2012, 0:00 – Present	CSV
Loop	1	Jan. 1, 2012, 0:00 – Present	CSV
ATR	60	Jan. 1, 2014, 0:00 – Present	Database (CSV)

1.3.1. TomTom Custom Travel Times

The TomTom Custom Travel Times (CTT) tool offers historic travel times on a specified route based upon TomTom's proprietary mix of probe data sources. These sources include high-frequency GPS (global positioning system) data provided by TomTom's in-vehicle GPS systems as well as a variety of other sources. Once a route (with direction), date range, and time period are selected, historic data are processed and provided in a variety of data formats including Google KML (Keyhole Markup Language), Microsoft Excel spreadsheet, and ESRI shapefile. Data are primarily used to view travel times and travel speeds for the entire route, although a breakdown of speeds by segment[4] of the route is provided. Data in the processed files cannot be disaggregated by fewer dates / smaller time periods than those used in the request, making comparison of segment-time periods for detailed statistics impractical. Sample sizes are provided as segment averages over the entire date range. Vehicle classifications are split into passenger and fleet management vehicles, although the TomTom source pool weighted toward passenger devices/vehicles more than fleet vehicles.

---

[3] See Analysis Plan Table 4 for details
[4] These segments are OpenLR segments used by TomTom and are not related to TMCs or other segment types

1.3.2. TomTom Live Traffic Archive

The TomTom Live Traffic Archive (LTA) tool offers real-time and historic travel times on all routes and features the same data sources as other TomTom products including the CTT tool. Data from this tool is downloaded on a statewide[5] basis, but like the CTT allows for selection of data range and time period. Data are processed as a protocol buffer with location referencing in the OpenLR format.[6] The procedure to access these files is discussed in Appendix A. Data are used to view travel times and travel speeds for portions of a route, by any time period subset. Confidence intervals are provided with each travel time and corresponding speed for a segment.

1.3.3. Bluetooth Reidentification

Bluetooth detectors scan the covered area and check if any Bluetooth-enabled devices are detected. Once a vehicle equipped with a visible Bluetooth device drives into the detection range of the Bluetooth detector, a time-stamp is recorded for that vehicle. The same happens again at the next detector. In re-identifying the same vehicle at the second detector, a travel time is calculated for that vehicle, which can also be recorded as a speed when the distance between detectors is known. Because of this method of detection, data can also be used for origin-destination studies in addition to travel time and speed studies.

1.3.4. National Performance Management Research Data Set

The National Performance Management Research Data Set (NPMRDS) is a free dataset provided through the Federal Highway administration by a third-party data provider. The original implementation, which was used for this study, was provided by HERE and included travel times and speeds in five-minute intervals. Data are provided for download to state agencies on a monthly basis. The original NPMRDS through HERE offered no probe observation count, however the new 2017 version, provided by Maryland's Center for Advanced Transportation Technology (CATT) Lab using INRIX data, is expected to offer a range of reporting vehicles known as a Data Density Indicator. Data are primarily used to view travel times and travel speeds for portions of a route, by any time period desired. Data are intended to support performance management analysis and reporting, available by highway segments called TMCs (Traffic Message Channel links). Data from the NPMRDS tool do not include real-time information and are used in this project for comparing travel times with other sources.

1.3.5. Inductive Loops

Inductive loops are a technology that is heavily used for stop bar detection at traffic signals. However, they can also be used as traffic counters, and as such have seen application on routes other than urban arterials. Dual-loop technology, where two loops are placed near each other along a route allows for the calculation of travel times using time-mean speeds. Loops provide volume, speed, and occupancy values that can be used for a variety of applications. Multiple loop configurations must be used if there are multiple lanes on a facility to allow for all vehicles to be counted.

---

[5] This area corresponds to the purchased area of the dataset based on contractual agreement

[6] See the OpenLR website for more information, http://www.openlr.info/

1.3.6. Microwave Radar

Microwave radar offers the benefits of dual- loop detection without physical installation into the roadway. Microwave sensors detect vehicles on the roadway within their coverage range using methods similar to other radars used in speed detection and can be used to calculate volume, speed, and occupancy. Thus, like inductive loops, microwave detectors have a wide range of applications.

1.3.7. Automatic Traffic Recorders

Automatic traffic recorders are used to count vehicles on a facility and can also be used for vehicle classification. These systems either remain in one location (continuous counts), or are transferred to different locations to do 48-hour coverage counts. For this study, ATRs were simply used as a baseline vehicle count for each roadway

1.3.8. Other Travel Time Technologies

The Literature Review (Appendix C) includes details on other travel time technologies not used in this study, including camera detection, license plate readers, and Wi-Fi technology.

1.4 Study Area

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 1.2 and Figure 1.1. TomTom and NPMRDS data are available on all routes and Bluetooth data are 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 1.1 with a circle, as the route is short and difficult to see.

Table 1.2. Selected Routes for the Travel Time Technology Evaluation with Data Types

Corridor	Start/End	Location	Route Type	Data Types
US 12/18	I-39/90 to WIS 73	E. of Madison	Rural Prin. Arterial	TT, NPMRDS, BT
US 14 (M)	US 12/18 to Co. MM	Fitchburg	Suburban Freeway	TT, NPMRDS, BT, ATR
County M	US 18/151 to Co. MM	Fitchburg/Verona	Rural Min. Arterial	TT, NPMRDS
US 14 (J)	I-39/90 to WIS 140	E. of Janesville	Suburban Prin. Arterial	TT, NPMRDS, BT, ATR
WIS 73	I-39/90 to WIS 106	Albion	Rural Min. Arterial	TT, NPMRDS, μwave
US 151	Blair to Portage	Madison	Urban Prin. Arterial	TT, NPMRDS, BT, ATR
I-39/90	IL Border to I-94	Dane/ Rock Co.	Rural Freeway	TT, NPMRDS, BT, μwave, ATR
US 12	I-39/90 to Parmenter	S. of Madison	Urban Freeway	TT, NPMRDS, BT, μwave, Loop, ATR

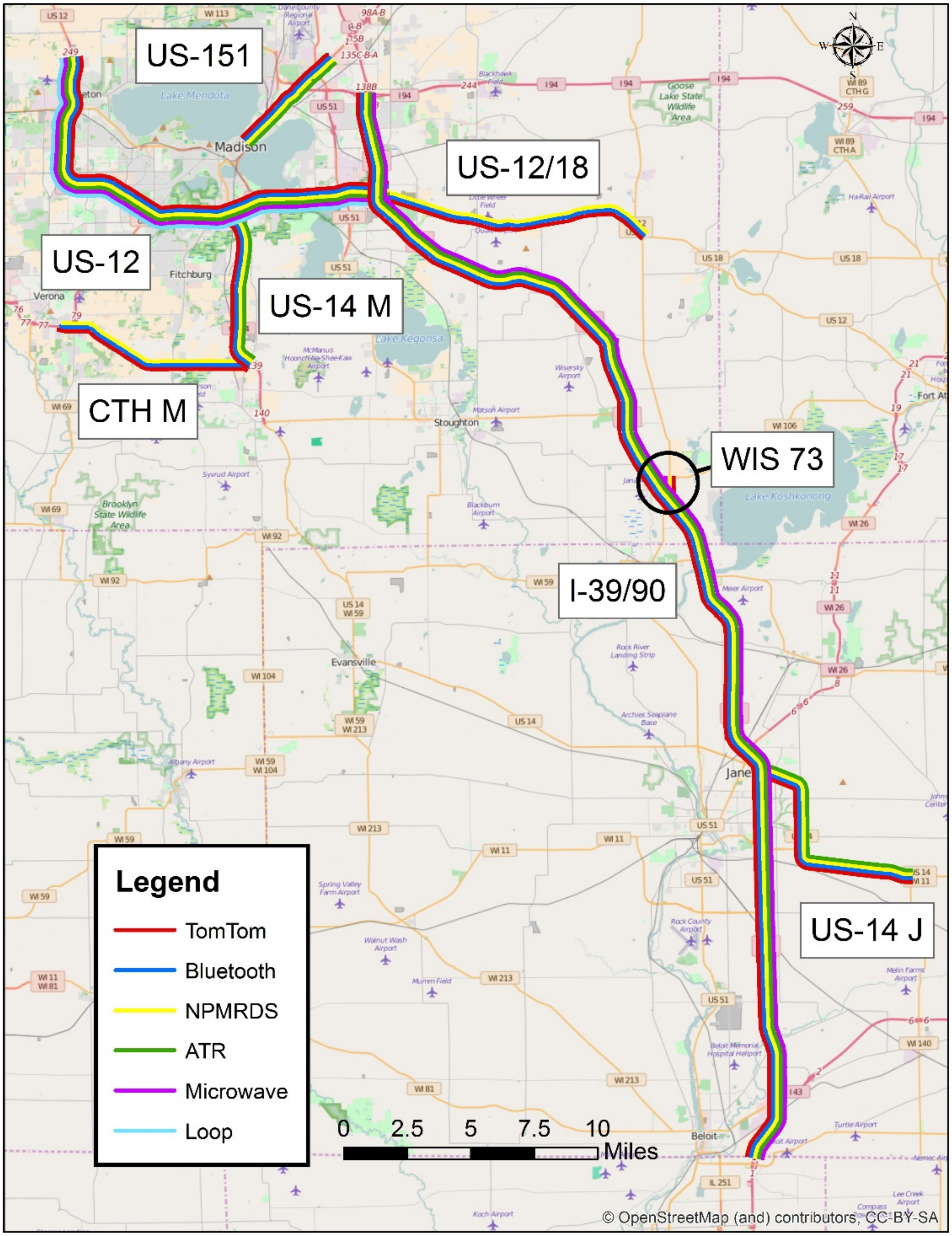


Figure 1.1. Travel Time Technology Evaluation (T3E) Route Overview Map

1.5. Study Time Periods

To make sure that statistical comparisons are as consistent as possible, specific dates and times were chosen for the analysis. These dates were 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 1.3. Both months used as periods for all but one corridor include a holiday, either Memorial Day or Independence Day.

Specific study time ranges within the chosen time periods are used for comparisons 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, 9:00am - 3:00pm
- Weekend Daytime, 7:00am - 7:00pm
- Nighttime, 8:00pm - 4:00am

Table 1.3. Selected Date Ranges for Study by Corridor

Corridor	Start/End	Available Period	Chosen Periods
US 12/18	I-39/90 to WIS 73	04/15/2015 to 05/04/2015	04/15/2015 to 05/04/2015
US 14 (M)	US 12/18 to Co. 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 Co. MM	04/14/2015 to Present	05/01/2015 to 05/31/2015 and 05/01/2016 to 05/31/2016
US 14 (J)	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
US 151	Blair to Portage	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	04/14/2015 to Present	05/01/2015 to 05/31/2015 and 05/01/2016 to 05/31/2016

2. Data Quality Comparison

This section includes a data quality analysis looking at various elements that affect data quality. Ease of access including access methods, available data formats, and available information is presented in Section 2.1. Latency for real-time application of travel times is discussed in Section 2.2. Reliability of detection technologies including consistency, missing data, and incorrect data is the focus of Section 2.3. Ability to archive data is briefly discussed in Section 2.4. Equipment durability for hardware maintenance is presented in Section 2.5.

Another important measure of data quality is data availability, including sampling rates and usable travel time percentages. This topic is detailed in depth in Section 3 of this report. Accuracy of travel time and speed reporting using statistical analysis is included in Section 4. Together, Sections 2 through 4 of this report outline the benefits of each of the detection technologies used to calculate travel times.

This quality analysis is not meant to replace WisDOT's current travel time validation procedures, and instead is meant as a precursor to such activities. WisDOT's Bureau of Traffic Operations (BTO) already validates travel times on all travel time routes annually. This review uses data from field runs that capture travel times with a stopwatch or a GPS application. The review also uses travel time data collected concurrently by Google Maps and BTO's Advanced Traffic Management System (ATMS) for comparison. The Bureau's annual maintenance contract includes a review of each detection site. Speeds are checked against a radar gun and vehicle detections observed at the site during the visit. This study aims to support travel time comparisons up front before technologies are integrated into the ATMS.

2.1. Ease of Data Access

Data was acquired from all sources using various means. This section summarizes the data available and access basics for each data source. Overall, the easiest data to access is NPMRDS, followed by microwave and loop data (through WisTransPortal) and Bluetooth (through the Drakewell interface). TomTom data was hardest to access and involves a cost for each distinct dataset that is accessed.

Each tool requires a certain level of established access privileges in order to access the data, and none of the sources are open-access except for ATRs. Each sub-section below discusses the data access procedure. It should be noted as well that some of these technologies require a fair amount of knowledge, training time (e.g., tutorials, support), and testing to figure out how to use effectively.

2.1.1. TomTom CTT (Custom Travel Times)

Access Point: TomTom, http://trafficstats.tomtom.com/
Access Requirements: WisDOT client login and password
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 2.1, 2.2, and 2.3

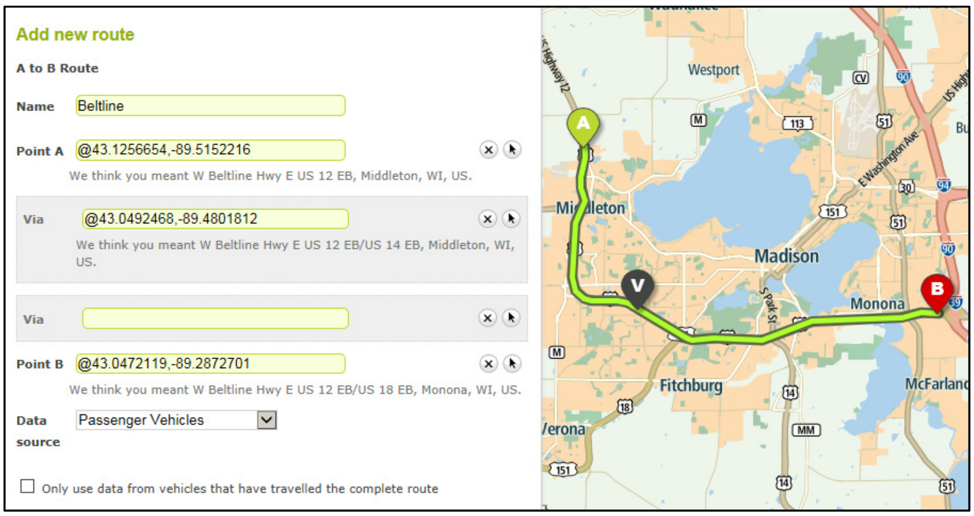


Figure 2.1. Data Access Screen (Routes) for TomTom Custom Travel Time Tool

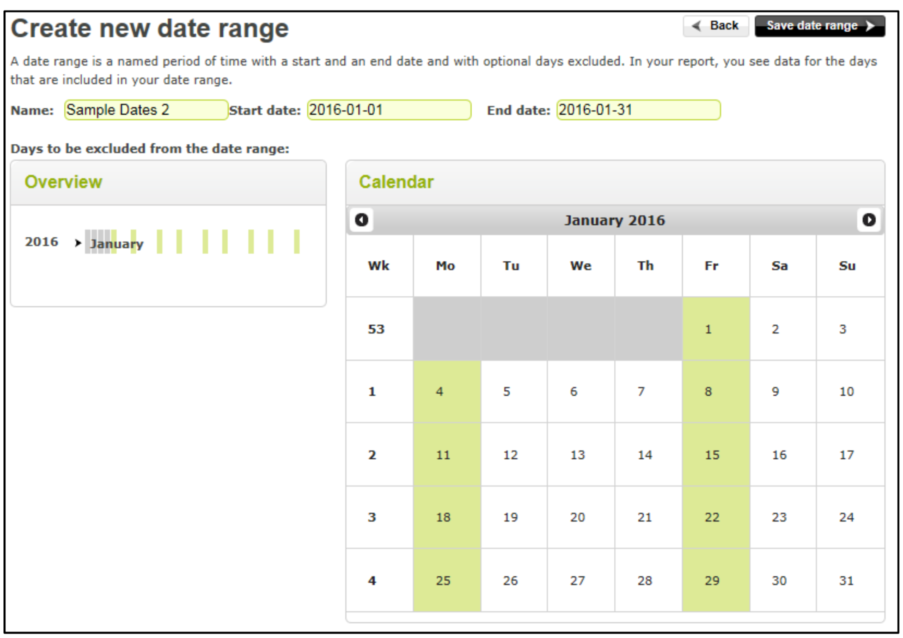


Figure 2.2. Data Access Screen (Dates) for TomTom Custom Travel Time Tool

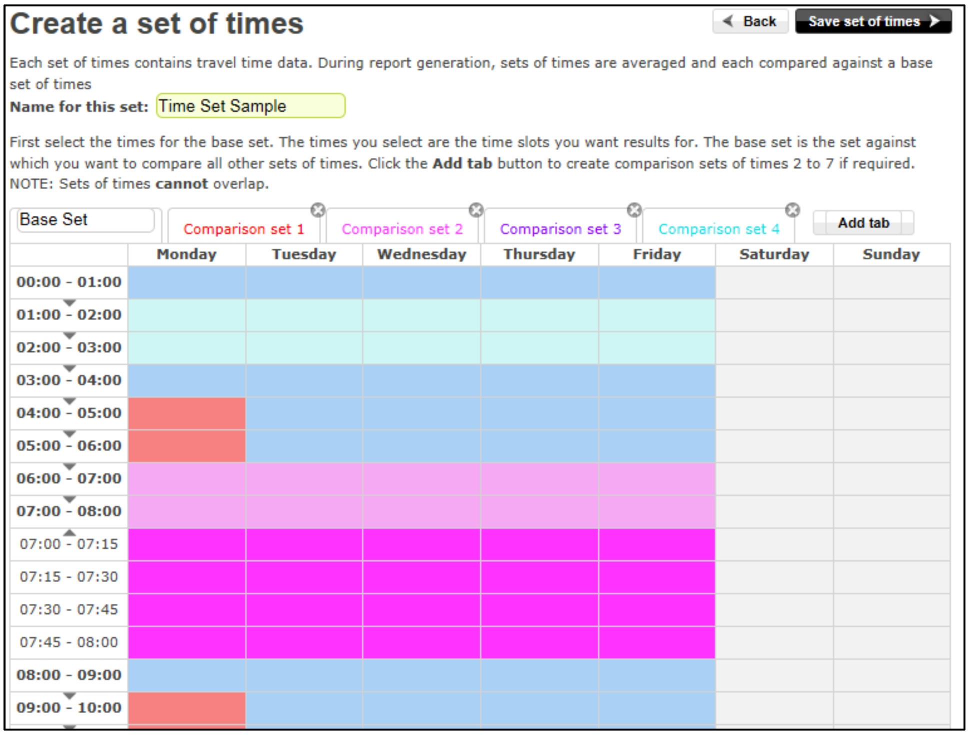


Figure 2.3. Data Access Screen (Times) for TomTom Custom Travel Time Tool

2.1.1 TomTom LTA (Live Traffic Archive)

Access Point: TomTom, http://trafficstats.tomtom.com/
Access Requirements: WisDOT client login and password
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 2.4

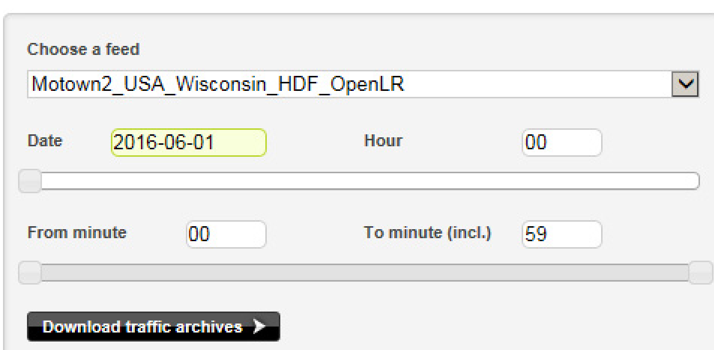


Figure 2.4. Data Access Screen for TomTom Live Traffic Archive Tool

2.1.3. Bluetooth

Bluetooth data are accessed using Drakewell's C2-Cloud Traffic Data online suite. This software provides many different access points to the data. For this study, the Journey Time Zone to Zone Matches tool is used to collect data. The zone to zone match queries contain historical data rather than real time data. Zone to zone matches include all historic data, even data that was not available for some reason during real-time, so data included in this study will include more matches than is typically seen in real-time application of Bluetooth travel times. This is discussed further in Sections 2.3.2 and 3.2.2.

Access Point: Drakewell, https://drakewell06.drakewell.com/
Access Requirements: Client login and password
Access Settings: Bluetooth units, dates, times
Interval Size: 1 minute
Dates Available: Route Dependent
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 2.5

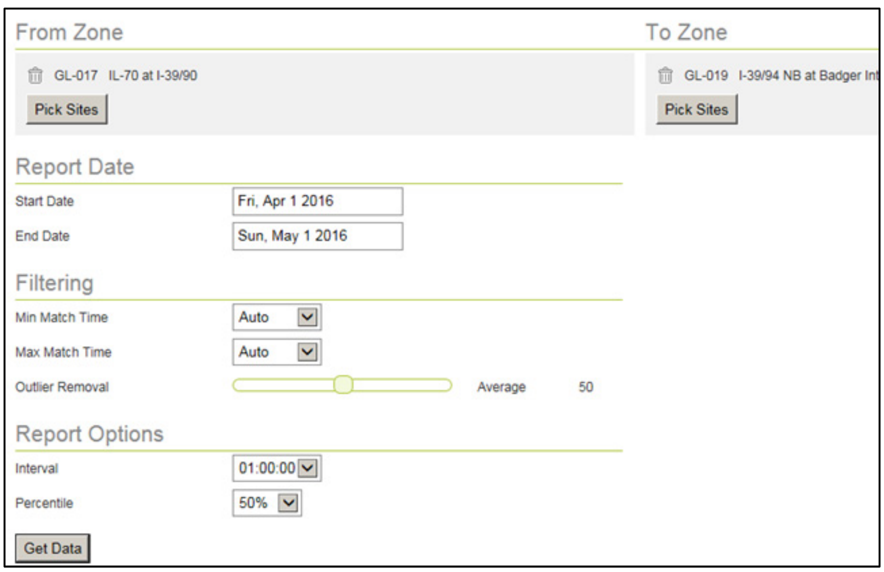


Figure 2.5. Data Access Screen for Bluetooth Data (using Drakewell Online)

2.1.4. NPMRDS (National Performance Management Research Data Set)

Note that the following information is based upon NPMRDS 1.0 which has provided data through January 2017. NPMRDS 2.0 offered through CATT Lab's Regional Integrated Transportation Information System (RITIS) has separate access methods that requires a data sharing agreement and a user account to access the data. NPMRDS 2.0 became available July 2017 and provides data from February 2017 onward.[7]

Access Point: FHWA, https://here.flexnetoperations.com/control/navt/emailnotice
(Data downloaded and then stored in Oracle database)
Access Requirements: State DOT client login and password
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: TMC segments
Data Format: Comma Separated Value (CSV) (static file and travel time data file)
Information Provided: Travel Time
Data Access Screen: See Figure 2.6

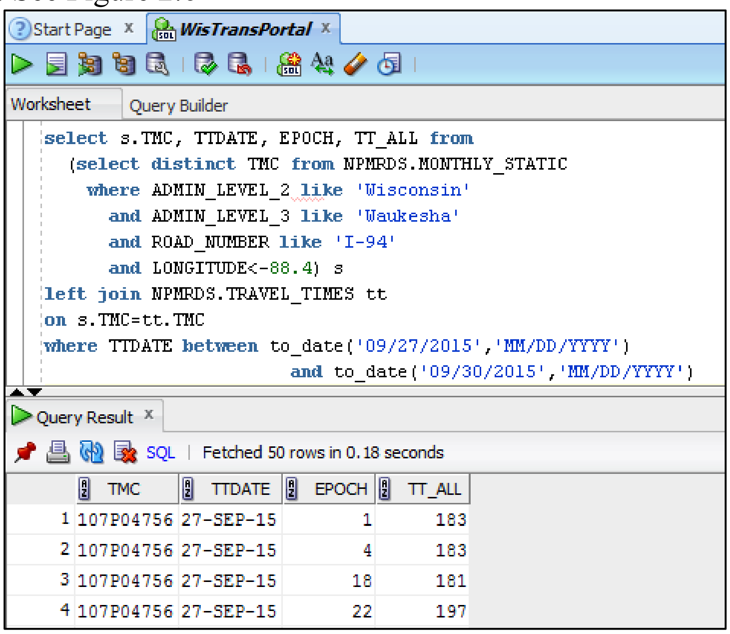


Figure 2.6. Data Access Screen for NPMRDS (using Oracle SQL Developer)

2.1.5. Microwave/Loop

Access Point: TOPS Lab Volume, SPeed, and OCcupancy (V-SPOC),
http://transportal.cee.wisc.edu/applications/V-SPOC/
Access Requirements: Client login and password through TOPS Lab
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

[7] For more information, refer to the RITIS NPMRDS website, https://npmrds.ritis.org/analytics/.

Data Format: Comma Separated Value
Information Provided: Volume, Speed, Occupancy
Data Access Screen: See Figures 2.7 and 2.8

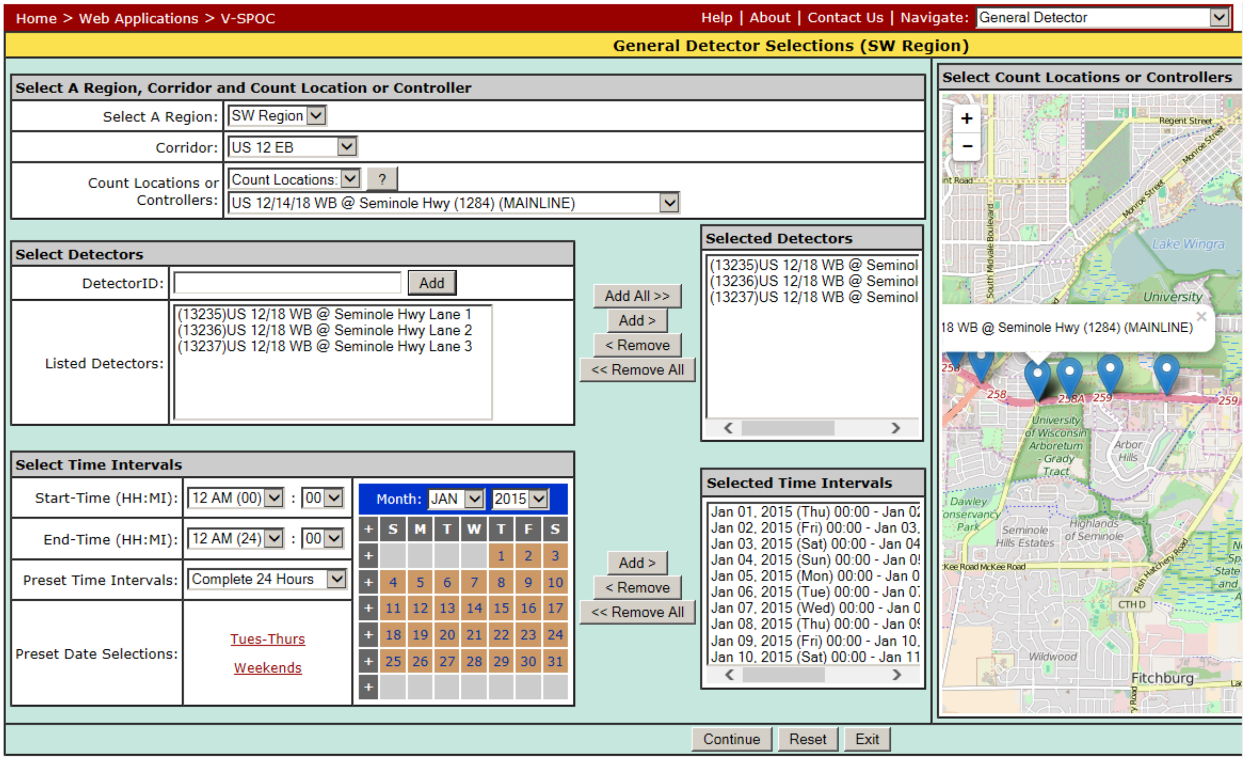


Figure 2.7. Data Access Screen 1 for Microwave/Loop Data (using V-SPOC online)

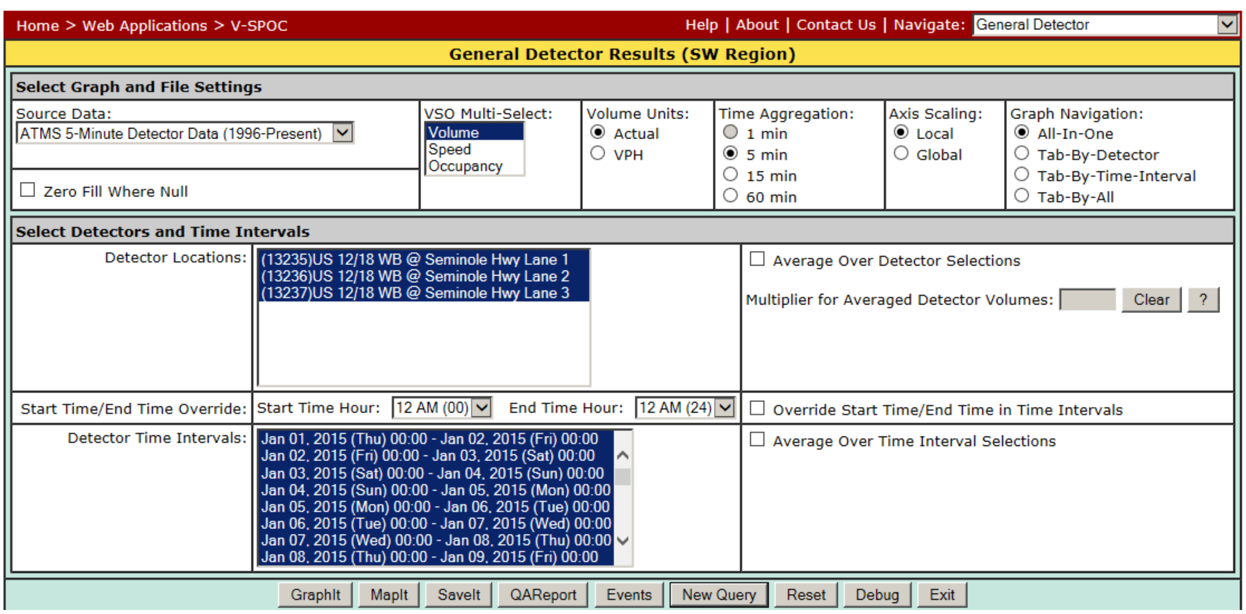


Figure 2.8. Data Access Screen 2 for Microwave/Loop Data (using V-SPOC online)

2.1.6. ATR (Automatic 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 Requirements: Open Access
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, Classification
Data Access Screen: See Figure 2.9

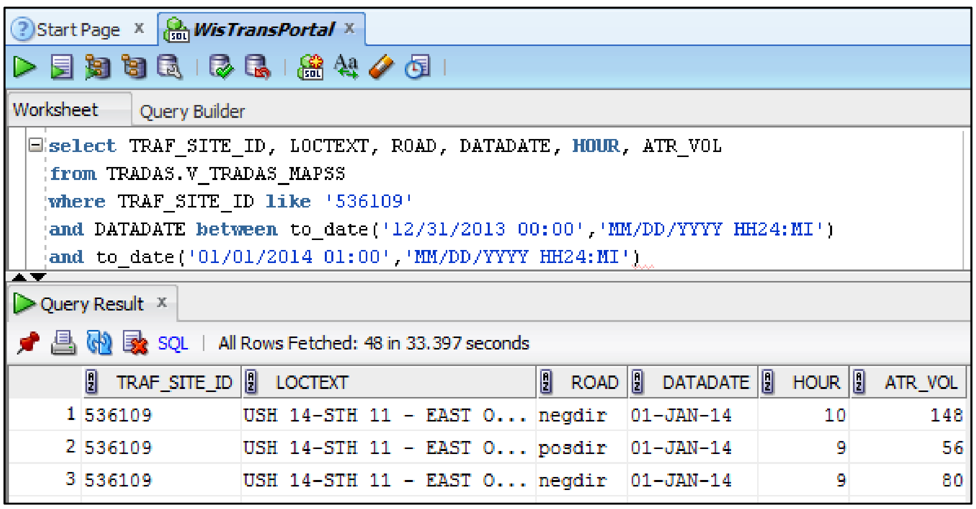


Figure 2.9. Data Access Screen for ATR Data (using Oracle SQL Developer)

2.2. Latency for Real-Time Application

Latency is a critical data quality measure when providing real-time data to the traveling public. Even if a calculated travel time perfectly reflects the traffic situation, a delay of a few minutes can make these numbers meaningless, especially during rush periods where queue lengths are constantly changing which can severely affect travel times.

Although some times are constant among travel time technologies, others vary considerable. Agency software processing of the data induces latency into the travel time delivery process. Processing times for data aggregation and delivery are in the range of one to three minutes depending on where the data are headed, either to a DMS or to 511. This latency is similar for all technologies. Other aspects of latency for each detection technology is discussed below.

2.2.1. TomTom

TomTom offers many historic travel time tools, but also offers real time traffic information. Latency is minimal, as many probe sources of the information are being updated frequently as the vehicle moves down the highway and there is no fixed hardware. Networking speeds do add milliseconds to the delay, but overall TomTom travel times can be updated in seconds. This makes TomTom and other third party provided data very attractive in terms of latency, as the bottleneck is the delivery itself and not the acquisition of data.

2.2.2. Bluetooth

Bluetooth data has a built in latency due to vehicle re-identification. Therefore, latency depends directly upon distance of units and typical speeds of traffic. On interstates, units placed one mile apart will require roughly one minute to re-identify a vehicle and produce a travel time. As travel speeds slow with congestion, this latency will increase. The only way to get a travel time faster would be to place units closer together, which increases system cost. On urban arterials, units could be placed at each intersection, and latency is much lower. Especially on a deployment such as East Washington, this would mean latency would be around 15-30 seconds. Latency of networking is minimal in all of these scenarios, as this delay is typically measured in milliseconds. Standard data processing times still apply.

2.2.3. NPMRDS

The major drawback of NPMRDS is the lack of availability for real-time use. Therefore, latency is essentially 3-7 weeks or more, making it impractical for applications that require real-time data.

2.2.4. Microwave/Loop

Microwave and dual loop detectors that can detect traffic speeds and estimate travel times based on point detection also are attractive in terms of low latency. Loop detectors in a dual loop configuration are placed only feet apart as opposed to a quarter mile or more apart as is the case with Bluetooth detectors. This makes latency as far as producing a spot speed very low. Networking delay is minimal, however data are only processed every 20 seconds with data feeds updated each minute. So this style of detection due to processing time has slightly better latency than Bluetooth and TomTom detection.

2.3. Reliability of Data Stream

The word reliability can be used in many ways in assessing travel time data. The term reliability as used in this report refers to data's reliable use, not to travel time reliability as may be calculated from the travel time observations. The topic of reliable data use focuses on missing data, incorrect data, and data consistency. Unavailable data as a result of no observations is addressed in Section 3 of this report.

Travel times are often unavailable because of technical issues, for example software integration bugs or field device outages. An example of this is a software update that caused several routes to lose travel times due to link outages on multiple occasions in spring 2017.

Table 2.1 depicts a summary an 11-week period of travel time availability for several routes during this time period, generated variously by TomTom, Bluetooth, and microwaves/loops. The table shows the percentage of days that outages are between the percentages shown in the first column of the table. For example, TomTom Route 3847 has between 0 and 10% missing travel time data 39% of the days between March 1 and May 16, 2017. As can be seen in the table, there are events that occur resulting in missing data. The final two rows of the table show the average percent of outages over the entire period and the percentage of hours where at least 1% of units have an outage. More information from the table on specific data sources is included in the sections below.

Travel time routes with more links are more reliable. WisDOT requires that 2/3 of the links must be available to provide a travel time. The more links, the more allowances for outages. However, outages are still a problem that must be addressed between technologies.

Table 2.1. Sample Missing Data Percentages for March 1-May 16, 2017

Travel Time Outage (%)	TomTom			Bluetooth		Loop / Microwave	
	3843	3847	3853	3525	3741	3734	3872
0-10	77.9	39.0	83.1	87.0	92.2	100.0	97.4
10-20	5.2	0.0	1.3	6.5	5.2	0.0	2.6
20-30	3.9	2.6	2.6	0.0	0.0	0.0	0.0
30-40	1.3	1.3	1.3	0.0	0.0	0.0	0.0
40-50	1.3	0.0	1.3	3.9	1.3	0.0	0.0
50-60	0.0	1.3	0.0	0.0	0.0	0.0	0.0
60-70	0.0	1.3	0.0	0.0	0.0	0.0	0.0
70-80	6.5	14.3	6.5	1.3	0.0	0.0	0.0
80-90	3.9	40.3	3.9	1.3	1.3	0.0	0.0
90-100	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	**11.7**	**47.4**	**10.6**	**6.4**	**3.5**	**0.1**	**0.4**
Percentage of Hours at Least 1% Outage	**45.5**	**70.1**	**27.3**	**83.1**	**61.0**	**1.3**	**2.6**

2.3.1. TomTom

TomTom data are generally very reliable on the data stream end of the transmission, as TomTom samples data from multiple probes on the route. As long as a route has enough traffic that can be detected by TomTom, data can be reported. Therefore, the biggest problem with reliability of TomTom data comes in their internal storage and processing of data, and the stream of data between TomTom and the DOT.

TomTom's precise method of filling in missing data is proprietary, so discovering missing data at TomTom's end is difficult. However, missing data due to software glitches has shown to be an occasional issue, which is depicted in Table 2.1. Route IDs 3843 and 3853 demonstrate a TomTom-related outage March 21-24, 2017. Route 3847 lost data April 4, 2017 as link updates were stalled because of an incorrect version delivery that was not corrected for six weeks. Upon reviewing TomTom's travel times, incorrect data seems to be mostly filtered out, as all times, even 5^{th}-percentile and 95^{th}-percentile travel times, are generally very reasonable.

TomTom's source pool is weighted toward passenger devices/vehicles more than fleet vehicles, which will result in faster travel times than are necessarily average especially on heavy truck routes such as I-39/90. TomTom's data are also anonymous, so there can be issues with double-counting vehicles "looping" on the same route within the time period, where all visits count towards the average. This is generally not a problem unless using full traversal mode, which is not recommended.

2.3.2. Bluetooth

As Bluetooth data are collected from physical hardware, there can be data outages as a result of battery charge failure, solar panel failure, other hardware failure, removal/relocation due to construction, or communications interruptions. In the worst case, crashes can destroy the hardware, as happened to a GLRTOC unit in Illinois in 2016. If a Bluetooth unit goes down, two travel segments go down as each unit is both the start of one segment and the end of another, which makes failure more problematic especially on routes with few such segments. As shown in Table 2.1, data loss for Bluetooth routes can occurs occasionally, and in this specific example the data loss occurred between April 1-3, 2017 due to an error processing data, as the Drakewell XML feed was working.

If data loss occurs due to a communications error, and the Bluetooth unit is still collecting data, data are repopulated on the server once it is available. Thus, when using historic matches, real-time availability can be artificially inflated. Although this is not missing data, the effect is the same. This is discussed in more detail in Section 3.2.2.

Incorrect data with Bluetooth detectors can be a significant problem is outliers are not dealt with effectively. For instance, reports some very high times if outliers not removed. This is likely due to a few different problems with re-identification, such as drivers stopping on route to shop for an hour, then continuing past the second detector, or vehicles that pass one detector, take an alternate circuitous route, and then end up at the second detector much later. If Bluetooth detectors are placed too far apart on a route, especially an arterial route with many options for accessing and departing from the route, there are many potential probes that are missed as they are never re-identified.

Bluetooth also has an issue with detections at intervals smaller than the total travel time required to complete a segment. Thus, certain segments include very few matches during 5-minute intervals, so using larger time-intervals is recommended.

2.3.2. NPMRDS

NPMRDS version 1.0 is a heavily processed dataset provided by HERE, thus assessing missing data is difficult, although there do appear to be cases in the data provided where travel times are unreasonably high, e.g., with the recurring instances of travel times equivalent to 1 km/hr.[8] For example, a travel time was recorded on County M of 6.8 hours for a 4 mile segment. Being NPMRDS is not used for real-time application, reliability of data is not critical to this study.

2.3.4. Microwave/Loop

Microwave detectors suffer from similar reliability issues as do Bluetooth detectors in that hardware issues are a prominent reason these detectors could lose data for long periods. Communications issues are also prevalent with microwave and loop detectors, although unlike Bluetooth units, microwaves and loops do not store values until connectivity is resolved. The loop/microwave example shown in Table 2.1 show that this detection method is generally more reliable than other methods. Both of these technologies also benefit from being mature and well understood technologies. In addition, loops are generally insensitive to weather events.

2.4. Ability to Archive Data

This section briefly outlines the ability to archive data. Data archiving is important for many reasons including usage for public inquiries, quality assurance/quality control (QA/QC), research activities, and performance reporting. In addition to individual technology archiving, as shown below, 511 travel times are also archived through the WisTransPortal.[9]

2.4.1. TomTom

TomTom data are archived in real-time on the TomTom Traffic Stats system and available for use. Archived data via the CTT tool, however, involves difficult and costly processing to access. For instance, data were provided from this tool for use on another WisDOT project, and 32 credits were used for this one data request. The TomTom LTA tool offers better archive access, although at the cost of sophisticated data processing software.

2.4.2. Bluetooth

Bluetooth data are archived by Drakewell for easy access to matches between any two detectors on the system as soon as it is connected. However, as discussed previously, archived data includes all data acquired by the Bluetooth devices including data that was not necessarily available for use in real-time. This real-time archiving is available for WisDOT detectors for 30 days and for GLRTOC detectors for one hour, so any study requiring this data needs to capture it near real-time in order to archive in another fashion.

---

[8] GLRTOC Comments on MAP-21 NPRM for Part 490

[9] https://transportal.cee.wisc.edu/applications/travel-times/ (password protected)

2.4.3. NPMRDS

NPMRDS is not available in real-time and thus is only available in archived form. All NPMRDS data since its inception in 2013 is stored on TOPS Labs servers and accessible through Oracle database.

2.4.4. Microwave/Loop

Microwave and loop detector data are available in archived form through the WisTransPortal's V-SPOC application. Data are accessible for all routes, time periods, and time intervals and is available since the inception of these technologies, back as far as 1996. Thus, archiving of this data is a mature process that allows for easy extraction of data for many purposes.

2.5. Durability of Equipment

This section briefly outlines equipment durability in the frame of maintenance and life-cycle replacement for each technology.

2.5.1. TomTom

On the face, TomTom is the most durable because there is no physical equipment to install. So the fact that TomTom is the best technology in terms of durability of equipment is true. Technically, individual probes (e.g., in-car TomTom navigation units) do fail and need to be replaced, this is not a burden on the DOT. Also, there are so many probes on the roads with that number increasing every year, so individual probe failure is not an issue.

2.5.2. Bluetooth

Bluetooth detectors have many hardware components, all of which can fail under different circumstances. Although most computer hardware is housed in protective casing, elements can damage or cause issues with the equipment. Hardware issues include battery failure, processor/circuit board failure, solar panel failure, and physical connection failures. Also, as can be seen in Table 2.1, half of the time there is usually at least one detector malfunctioning, which makes a maintenance contract a necessity. In addition, the poles that these detectors are attached to are subject to severe weather, crashes, and other reasons for removal.

2.5.3. NPMRDS

Similar to TomTom, NPMRDS data are derived by HERE and moving forward will be derived from INRIX. Being there is no hardware for the DOT to replace, there is no cost associated with durability of equipment. However, with federal contracts for this data being replaced every few years, there is significant cost in maintenance of the data due to large changes in data processing.

2.5.4. Microwave

Microwave detectors, like Bluetooth detectors, have many hardware components, all of which can fail under various circumstances. Microwave detectors are typically smaller than Bluetooth detectors, but still are subject to the elements and their poles being damaged or removed. Batteries are typically much smaller, easier to replace, and do not weigh down the housing.

2.5.5. Loop

Loop detectors are very durable, and if installed correctly, will last as long as the pavement they are cut into. Loop detectors are not susceptible to most weather events and are built to sustain constant tire wear. Being they are hardware devices, they are still subject to maintenance and replacement, but are certainly more durable than Bluetooth or microwave detectors. One disadvantage to loop detectors is that they cannot be moved between sites once installed, which is an advantage of microwave and Bluetooth detectors.

3. Data Acquisition and Availability

This section includes all data availability measures for the data acquired from all sources. Section 3.1 discusses the data availability measures used for this project. Section 3.2 summarizes the data acquisition and processing process. Section 3.3 reports on findings from the data availability analysis and includes all data availability tables. Section 3.4 explains the online interactive tool which shows the data availability numbers in a graphical format.

3.1. Data Availability Overview

Data availability is presented in a number of ways in this report. These are outlined below.

Total vehicle count. This value shows how many vehicles are counted on the route per hour and per segment or detector. For example, if 22.9 vehicles per segment per hour are reported for northbound US 151 for the AM rush period on a route, this means that on average 22.9 vehicles are recorded on each segment on the route during the average hour of the given time period.

Total vehicle percentage. This value shows what percentage of vehicles counted on the route per hour per segment or detector. This value is taken as a percentage of the ATR counts, the microwave/loop counts, or an average of the two if available. For example, if 9.3% of vehicles were detected for northbound I-39/90 for the AM rush period on a route, this means that 9.3% of the average of ATR and microwave/loop counts were counted by this detection method for this time period.

Observation percentage. This value shows how many observations are available out of possible observations. The base unit is the smallest increment of time available for the given dataset on a given segment. For instance, for NPMRDS data, one observation is a single five-minute time interval on a single segment. The total number of these for a route during a given time period is equivalent to the total number of segments on the route multiplied by the total number of five-minute time intervals. As an example, if 72% of NPMRDS observations are available on a given route for a given time period, that means that if there are ten segments and ten time intervals available, 72 of the possible 100 segment-intervals have vehicles being detected on the route.

Usable travel time availability percentage. This value shows how many time intervals during a time period on a given route have calculable travel times. For example, if a route shows 95% of NPMRDS travel times available on a given route for a given time period, this means that a travel time is calculable for the entire route during 95 out of 100 time intervals. Continuing with the example in the previous paragraph, for a travel time to be calculable for a five-minute period, assume that at least two-thirds of the segments must be reporting a time. In that case, seven or more of the ten segments must have data for that route to have a travel time available. Referring to the illustrative example in Figure 3.1, note that availability on this route varies by segment, but that seven of the ten segments (with time periods c, d, and j being the exceptions) have more than two-thirds of the segments available, resulting in a 70% route travel time availability.

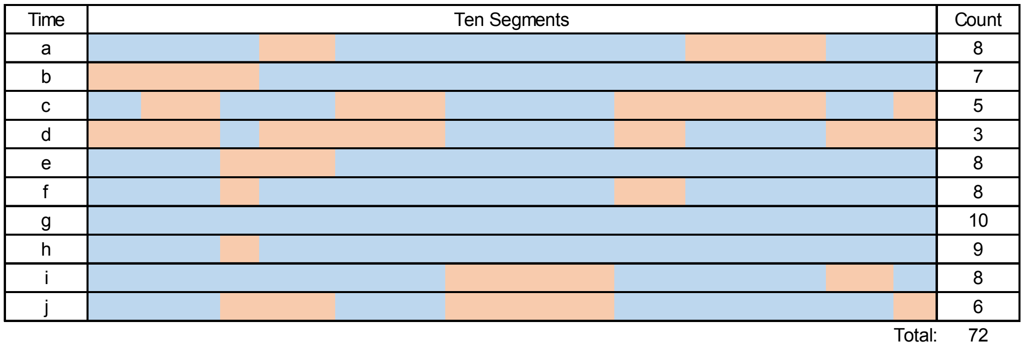


Figure 3.1. NPMRDS Usable Travel Time Availability Percentage Illustration

Observation percentage by segment or detector. This value is the same as the observation percentage, except it is calculated for each segment or detector instead of the entire route. For example, if 70% of NPMRDS observations are available on a given segment for a given time period, 7 of 10 time intervals have vehicles being detected on the segment. This value is not included in the report as there are nearly 3000 segments/detectors, but individual data are stored for the project and available upon request.

3.2. Data Acquisition and Processing

Each of the five primary data sources have brief descriptions in this section as to how data was acquired, processed, and placed into tables in Section 3.3 (data availability) and 4.1 (travel times). More detailed descriptions of acquisition of all data sources are shown in Section 2.1 and in the Analysis Plan, Section 4.1 (Appendix B). Appendix A describes data acquisition and processing of TomTom LTA data.

3.2.1. TomTom CTT

TomTom data from the custom travel time tool was downloaded by route, date range, and time periods. TomTom data from this tool comes pre-aggregated, meaning that travel times for specific segment-intervals are not available for use. TomTom data are offered using fleet passenger vehicles, fleet management vehicles, or a combination. As fleet management counts are limited, it is recommended to use all vehicles on the route for travel times. Also, although TomTom does not offer the numbers for segment-intervals, segments should still be used as data for vehicles traveling complete routes is limited, as would be expected for most long routes.

Steps for processing TomTom CTT data for the six categories used for availability and travel times are listed below.

- ***Total Vehicle Counts*** – Derived from sample size average per segment, divided by all of the time periods and dates across the study period.
- ***Total Vehicle Percentages*** – Total vehicle count as a percentage of total ATR or microwave/loop detector counts.

- ***Observation Percentages*** – Not available as segment-intervals are not available for TomTom CTT data and as such they are listed as unknown in the tables. It should be noted, that these could be studied on a small scale as multiple runs of data on short time periods could be used to aggregate the data in this manner, however this was not practical for this project and only a test-run of this was completed.
- ***Useable Travel Time Availability Percentages*** – Not available as observation percentages are not available. Shown as unknown.
- ***Average Travel Speeds*** – Taken directly from the Average Speed column included with TomTom data files, as aggregated by the CTT tool.
- ***Average Travel Times*** – Taken directly from the Average Travel Time column included with TomTom data files, as aggregated by the CTT tool.

3.2.2 Bluetooth

Bluetooth data was downloaded from Drakewell's C2-Cloud Traffic Data tool, both the version subscribed to by WisDOT and by GLRTOC, as appropriate for the given route. Zone-to-zone matches for journey times were used to acquire data by route segment and date range. Drakewell's default filtering was used, including automatic minimum and maximum travel time removals, outlier removal filtering of 50, and 50th percentile for reporting.[10] Testing was done as part of this project to select these values, as failure to filter outliers provides some very high travel times as discussed in Section 2.3.2.

This study uses historic Bluetooth matches which tends to over bias the percentage of data available in real-time. Many of the travel time outages that WisDOT has currently are not due to problems with the Bluetooth detectors failing, but in communication. When data flow is re-established, the database is populated with the historic data provided by the Bluetooth units, which means the historic data will include more data than was originally available.[11] The 100% values for BT shown in the observation and availability percentages charts in this section include retro-filled data for detector pairs and routes.

Steps for processing Bluetooth data for the six categories used for availability and travel times are listed below. Note that a scripting algorithm was used to aggregate most values discussed below.

- ***Total Vehicle Counts*** – Match count for each time period in the given time interval are summed for each segment and then adjusted and averaged across all segments.

---

[10] WisDOT software sets a threshold limit on speeds and look-back times for Bluetooth data processing in real-time data use. If bad congestion causes traffic to stop for extended time period, or if traffic is severely exceeding or under the speed thresholds, real time travel times will be omitted due to threshold settings. These thresholds are meant to prevent inaccurate travel times from being displayed when conditions change quickly, a crash blocks the roadway, or vehicles are speeding.
[11] WisDOT can query archived real-time travel times for up to one month, and GLRTOC units can only query this back to one hour.

- ***Total Vehicle Percentages*** – Total vehicle count as a percentage of total ATR or microwave/loop detector counts.
- ***Observation Percentages*** – Counts the total number of time periods during the given time interval on each segment where a match count is greater than zero, then divides this by the total possible time periods available during that time interval for those segments.
- ***Useable Travel Time Availability Percentages*** – Counts the total number of time intervals that have at least 2/3 of the segments (the threshold) with a match count greater than zero, then divides this by the total possible time periods available during that time interval.
- ***Average Travel Speeds*** – Each time period where a weighted sum of mean journey times is calculated (see below), a speed is calculated by dividing the segment length by the travel time. These numbers are averaged for all time periods in the time interval to report an average travel speed.

  Average Travel Times – The sum of all mean journey times (reported in the Drakewell files) during a time periods having enough segments reporting (2/3 – the threshold) is calculated and then weighted for the length of the full route. These numbers are averaged for all time periods in the time interval to report an average travel time.

3.2.3. NPMRDS

NPMRDS data was processed through TOPS Lab's Oracle database, which is maintained with all NMPRDS data available since its inception in 2013. NPMRDS data are delivered for each route by TMC segment. Data is provided by epoch, which is a five-minute period. Unlike other travel time detection methods, NPMRDS epochs that do not have any observations will just be vacant from the data file. Thus, processing is a bit different. Another drawback to NPMRDS 1.0 (which is changed in version 2.0) is that vehicle observation counts are not included in any form. Travel times for passenger, freight, and an aggregated vehicle group are available for each epoch with at least one observation, and the aggregated values are recommended.

Steps for processing NPMRDS data for the six categories used for availability and travel times are listed below. Note that a scripting algorithm was used to aggregate most values discussed below.

- ***Total Vehicle Counts*** – Not available as these data are not provided by HERE for NPMRDS version 1.0. Shown as unknown.
- ***Total Vehicle Percentages*** – Not available as total vehicle counts are not available. Shown as unknown.
- ***Observation Percentages*** – Counts the total number of epochs during the given time interval on each TMC segment where a row in the data exists (meaning the observation count is at least one). This number is then divided by the total possible time periods available during that time interval for those TMC segments.

- ***Useable Travel Time Availability Percentages*** – Counts the total number of time intervals that have at least 2/3 of the segments (the threshold) with an available travel time, then divides this by the total possible time periods available during that time interval.
- ***Average Travel Speeds*** – Each epoch where a weighted sum of travel times is calculated (see below), a speed is calculated by dividing the TMC segment length by the travel time. These numbers are averaged for all epochs in the time interval to report an average travel speed.
- ***Average Travel Times*** – The sum of all travel times during an epoch having enough TMC segments reporting (2/3 – the threshold) is calculated and then weighted for the length of the full route. These numbers are averaged for all epochs in the time interval to report an average travel time.

3.2.4. Microwave/Loop

Microwave and loop data are available through WisTransPortal and the V-SPOC tool. V-SPOC data are delivered for each route by detector, including volume, speed, and occupancy values for each time period. Because this detection method does not involve special hardware in the vehicle, nearly all vehicles are counted. However, unlike the other detection methods above, travel times need to be back calculated based on speed, which is a time-mean speed. Because the data are provided by the same tool, no distinction is made between microwave or loop detector values.

Steps for processing microwave and loop data for the six categories used for availability and travel times are listed below.

- ***Total Vehicle Counts*** – Volumes for all time segments in a given time interval across all detectors are averaged to provide a total vehicle count.
- ***Total Vehicle Percentages*** – These are not calculated for microwave and loop detectors as this percentage is assumed to be near 100%. These values are however used as the basis for all other total vehicle percentage calculations.
- ***Observation Percentages*** – Counts the total number of time periods during the given time interval for each detector where volume is greater than zero, then divides this by the total possible time periods available during that time interval for those detectors.
- ***Useable Travel Time Availability Percentages*** – Counts the total number of time intervals that have at least 2/3 of the detectors (the threshold) with a volume greater than zero, then divides this by the total possible time periods available during that time interval.
- ***Average Travel Speeds*** – Sums the speeds for each time period during the given time interval for each detector where volume is greater than zero, then divides this by the total possible time periods available during the time interval for those detectors. Note that because these are point speeds, all values are aggregated and the 2/3 threshold is not used.

- ***Average Travel Times*** – Being the value provided is a point speed, no attempt is made to derive segments and weight the average speed or travel time based on these. Instead, the total segment length is simply divided by the average travel speed to determine an average travel time for the route.

3.2.5. ATR

Automatic Traffic Recorder data are available through WisTransPortal and the TRADAS database. These data are delivered for each route by detector, with total vehicle counts aggregated by one-hour time period and day of the week for the given month. ATR data does not include travel speeds, thus speeds and travel times are not calculated.

Steps for processing ATR data for the six categories used for availability and travel times are listed below.

- ***Total Vehicle Counts*** – Total vehicle count is an average of all time periods during a given interval for the counts listed by appropriate day.
- ***Total Vehicle Percentages*** – These are not calculated for ATRs as this percentage is assumed to be near 100%. These values are however used as the basis for all other total vehicle percentage calculations. Note that when both ATR counts and V-SPOC counts are available, a weighted average of the two is used as the total vehicle percentage. Because total vehicle counts vary across the route, neither number is necessarily 100% for a given segment, so the weighted average is the best available approach.
- ***Observation Percentages*** – Not included as these values are not relevant seeing as travel times and speeds cannot be calculated. They are not available anyway as detector-intervals are not available due to data aggregation.
- ***Useable Travel Time Availability Percentages*** – Not included as these values are not relevant seeing as travel times and speeds cannot be calculated. They are not available anyway as observation percentages are not available.
- ***Average Travel Speeds*** – Not included because ATRs only include counts, not travel speeds or times.
- ***Average Travel Times*** – Not included because ATRs only include counts, not travel speeds or times.

3.3. Data Availability Tables and Discussion

This section includes data availability tables for each route. Section 3.3.1 summarizes detectors and time intervals, and sections 3.3.2 through 3.3.9 shows tables by route for all four data availability types discussed in Section 3.2. Key findings and notes based on table values are listed below with reference to specific tables or values when relevant.

There are many unavailable values shown in the tables.

Many tables include values listed as N/A. This means that the particular detection type on a specific route was not available for the study. To view a summary of these, refer to Table 3.1. More detail is also provided in Section 3.2.
For Tables 3.15 and 3.19, County M was not able to have TomTom total vehicle percentages calculated because there was no available count data (through ATRs, microwave detectors, or loop detectors) to compare to TomTom sampling counts. However, for routes like this, travel times are still available.

Point detection can miss key incidents for travel times.

Although microwave and loop detector data generally looks best for most measures of data availability, point detection can miss capturing slow traffic or jams on particular portions of the route. This gets particularly compounded on arterials, where stop and go traffic may not be measured by the detectors, showing a faster travel time.[12] There are also places where a traffic knot may be in between detectors, or a train crossing may block a highway for an extended period and not be near enough to a detector to be measured.

TomTom availability is improving.

TomTom data shows a trend of becoming more available from 2015 to 2016, likely due to increased coverage of their vehicle probes which should provide for more reliable travel times. This can be seen most directly for I-39/90's Total Vehicle Percentage Tables 3.39 and 3.43, where 2015 percentages from the 0-2% range increase to 3-13%.

Low total vehicle percentages do not equate to poor travel time estimates.

In most of the tables, observation percentages and available travel time percentages are much higher than total vehicle percentages. This is due to the way values are calculated. Total vehicle percentage is based on how many vehicles are detected out of all of those on the route. Observation percentage can be high as long as at least one vehicle is detected during most segment-intervals. This is important to consider as travel time availability does not necessarily affect quality / reliability. Just because there is a low sample rate (1% for instance), travel times are not necessarily inaccurate. The travel time analysis statistics in Section 4 show an analysis of this point.

Low travel time availability percentages are observed on some routes with high AADT.

In some cases, usable travel time percentages are very low even though observation percentages seem average. For instance, microwave/loop detection on US 12 has middling observation percentages, around 60% (Table 3.48), but usable travel times are very low, particularly for the eastbound direction where they are 0% (Table 3.49). This is due to a few situations combining to cause such a low number. WisDOT ATMS requires 65% of valid segments and 49.5% of

[12] Point detection (microwaves and loops) is not used by WisDOT on any arterials to provide travel times. These detectors are only used for real time travel times on controlled-access highways.

valid lanes to report a segment in the current ATMS travel time configuration. 2015 construction on US 12 included a lot of detection issues. For example, lanes with zero data, communication loss, temporary use, travel time route reconfiguration to exclude detectors reporting inaccurate data, and temporary decrease to 60% of required segments. While detector data was in a state of flux, the ATMS management team adjusted settings to maintain travel times. The ATMS limits the range of travel times to prevent travel times reflecting speeds higher than posted speed limit (PSL). Thus, travel times and speeds were still calculated as shown in Tables 4.24 and 4.25, using below the 2/3 threshold needed for reliable calculation. In these tables, speeds appear higher than other detection methods, likely due to the limited number of interval-segments available for calculation. This example addresses the link between data availability and quality of travel times.

Data availability tables should be used in conjunction with travel time tables.

These tables should be used in conjunction with the travel time tables in Section 4, as data availability and data quality are linked, but do high data availability does not necessarily indicate accurate travel times, as low data availability does not necessarily indicate inaccurate travel times. This is further discussed in the key findings of Section 4.

All data are available by request.

In all cases where values seem high or low, the data used to develop these tables is available upon request to review and determine why these numbers are not necessarily as expected.

3.3.1. Total Detectors / Segments and Time Intervals

Table 3.1 shows the number of detectors or segments used for each route. If the number shown is 0, that technology is not in use on the route. These segments were analyzed separately and averaged for data availability purposes. Table 1.1 shows the minimum time unit available for analysis for each detection type. A 15-minute time period was used to best match the availability all travel time detection technologies.

Table 3.1. Total Detectors/Segments by Route

Route	Route Type	TT – CTT (segments)	BT (detectors)	NPMRDS (segments)	µWave /Loop (count locations)	ATR (detectors)
US 12/18	Rural Principal Arterial	56 | 55	3	70 | 67	0	0
US 14 M	Suburban Freeway	42 | 38	4	33 | 32	0	1
County M	Rural Minor Arterial	60 | 59	0	37 | 37	0	0
US 14 J	Rural/Urban Principal Arterial	77 | 78	3	39 | 38	0	1
WIS 73	Rural Minor Arterial	7 | 9	0	6 | 6	1 | 1	0
US 151	Urban Principal Arterial	96 | 110	3	83 | 85	0	1
I-39/90	Rural Freeway	246 | 259	28	151 | 206	17 | 16	4
US 12	Urban Freeway	209 | 204	22	140 | 129	26 | 22	4

Note, when two numbers are present, order is NB | SB or EB | WB

3.3.2. Data Availability for US 12/18 (Rural Principal Arterial)

Table 3.2. US 12/18 Total Vehicle Counts, April 15 - May 4, 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	0.8 | 0.8	12.3 | 15.2	Unknown	N/A	N/A
AM Peak (07:30-08:30 M-F)	0.7 | 0.7	12.3 | 12.7	Unknown	N/A	N/A
PM Rush (15:00-18:00 M-F)	0.6 | 0.6	15.2 | 9.7	Unknown	N/A	N/A
PM Peak (16:30-17:30 M-F)	0.6 | 0.6	14.6 | 11.0	Unknown	N/A	N/A
Weekday Daytime (09:00-15:00 M-F)	1.5 | 1.6	12.4 | 12.1	Unknown	N/A	N/A
Weekend Daytime (07:00-19:00 S-U*)	0.5 | 0.4	8.2 | 8.3	Unknown	N/A	N/A
Nighttime (20:00-04:00 M-U)	0.1 | 0.1	2.3 | 1.5	Unknown	N/A	N/A

Units are in average number of vehicles per hour per segment or detector, EB | WB *U = Sunday

Table 3.3. US 12/18 Total Vehicle Percentages, April 15 - May 4, 2015

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	N/A	N/A	Unknown
AM Peak (07:30-08:30 M-F)	N/A	N/A	Unknown
PM Rush (15:00-18:00 M-F)	N/A	N/A	Unknown
PM Peak (16:30-17:30 M-F)	N/A	N/A	Unknown
Weekday Daytime (09:00-15:00 M-F)	N/A	N/A	Unknown
Weekend Daytime (07:00-19:00 S-U)	N/A	N/A	Unknown
Nighttime (20:00-04:00 M-U)	N/A	N/A	Unknown

Units are in percent (number of vehicles per ATR count per segment per detector), EB | WB

Table 3.4. US 12/18 Observation Percentages, April 15 - May 4, 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	92.9 | 92.9	43.0 | 41.5	N/A
AM Peak (07:30-08:30 M-F)	Unknown	92.9 | 92.9	43.1 | 43.2	N/A
PM Rush (15:00-18:00 M-F)	Unknown	94.6 | 94.0	37.6 | 32.8	N/A
PM Peak (16:30-17:30 M-F)	Unknown	92.9 | 92.9	33.0 | 30.2	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	98.2 | 99.7	43.6 | 39.9	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	96.2 | 96.5	11.6 | 10.3	N/A
Nighttime (22:00-04:00 M-U)	Unknown	57.7 | 42.2	4.1 | 4.0	N/A

Units are in percentage of segment time periods with at least one observation, EB | WB

Table 3.5. US 12/18 Usable Travel Time Availability Percentages, April 15 - May 4, 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	85.7 | 83.9	28.6 | 28.0	N/A
AM Peak (07:30-08:30 M-F)	Unknown	85.7 | 78.6	29.2 | 31.0	N/A
PM Rush (15:00-18:00 M-F)	Unknown	94.0 | 90.5	22.4 | 17.7	N/A
PM Peak (16:30-17:30 M-F)	Unknown	92.9 | 89.3	17.9 | 11.9	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	97.0 | 99.4	30.5 | 24.4	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	97.2 | 97.9	2.9 | 2.5	N/A
Nighttime (22:00-04:00 M-U)	Unknown	49.7 | 33.4	0.2 | 0.7	N/A

Units are in percentage of travel times calculable for entire corridor for the entire month, EB | WB

3.3.3. Data Availability for 14M (Suburban Freeway)

Table 3.6. US 14 (Madison) Total Vehicle Counts, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	0.9 | 1.2	14.7 | 50.4	Unknown	N/A	468 | 2097
AM Peak (07:30-08:30 M-F)	1.2 | 1.4	15.6 | 56.7	Unknown	N/A	545 | 2664
PM Rush (15:00-18:00 M-F)	1.1 | 0.9	42.0 | 19.9	Unknown	N/A	1858 | 651
PM Peak (16:30-17:30 M-F)	1.4 | 1.0	50.4 | 19.8	Unknown	N/A	2124 | 657
Weekday Daytime (09:00-15:00 M-F)	1.5 | 1.9	19.5 | 21.7	Unknown	N/A	612 | 645
Weekend Daytime (07:00-19:00 S-U)	0.8 | 1.0	14.1 | 16.1	Unknown	N/A	563 | 608
Nighttime (20:00-04:00 M-U)	0.1 | 0.1	5.5 | 3.4	Unknown	N/A	193 | 104

Units are in average number of vehicles per hour per segment or detector, EB | WB

Table 3.7. US 14 (Madison) Total Vehicle Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	0.2 | 0.1	3.1 | 2.4	Unknown
AM Peak (07:30-08:30 M-F)	0.2 | 0.1	2.9 | 2.1	Unknown
PM Rush (15:00-18:00 M-F)	0.1 | 0.1	2.3 | 3.1	Unknown
PM Peak (16:30-17:30 M-F)	0.1 | 0.1	2.4 | 3.0	Unknown
Weekday Daytime (09:00-15:00 M-F)	0.3 | 0.3	3.2 | 3.4	Unknown
Weekend Daytime (07:00-19:00 S-U)	0.1 | 0.2	2.5 | 2.7	Unknown
Nighttime (20:00-04:00 M-U)	0.0 | 0.1	2.8 | 3.3	Unknown

Units are in percent (number of vehicles per ATR count per segment per detector), EB | WB

Table 3.8. US 14 (Madison) Observation Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	98.0 | 100.0	36.8 | 53.2	N/A
AM Peak (07:30-08:30 M-F)	Unknown	96.0 | 100.0	36.0 | 55.7	N/A
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 100.0	44.5 | 38.9	N/A
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	41.9 | 39.8	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	100.0 | 100.0	37.9 | 47.2	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	98.9 | 99.4	13.2 | 17.7	N/A
Nighttime (22:00-04:00 M-U)	Unknown	78.9 | 66.5	3.8 | 4.1	N/A

Units are in percentage of segment time periods with at least one observation, EB | WB

Table 3.9. US 14 (Madison) Usable Travel Time Availability Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	97.6 | 100.0	33.9 | 59.3	N/A
AM Peak (07:30-08:30 M-F)	Unknown	95.2 | 100.0	32.9 | 61.1	N/A
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 100.0	42.3 | 40.2	N/A
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	38.5 | 42.9	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	100.0 | 100.0	35.6 | 49.7	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	99.2 | 100.0	10.3 | 18.5	N/A
Nighttime (22:00-04:00 M-U)	Unknown	77.6 | 68.5	2.7 | 3.7	N/A

Units are in percentage of travel times calculable for entire corridor for the entire month, EB | WB

Table 3.10. US 14 (Madison) Total Vehicle Counts, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	0.6 | 1.2	21.0 | 54.2	Unknown	N/A	496 | 2131
AM Peak (07:30-08:30 M-F)	0.7 | 1.6	21.0 | 59.7	Unknown	N/A	579 | 2683
PM Rush (15:00-18:00 M-F)	1.4 | 0.7	50.3 | 22.0	Unknown	N/A	1947 | 681
PM Peak (16:30-17:30 M-F)	1.8 | 0.6	59.2 | 21.3	Unknown	N/A	2236 | 696
Weekday Daytime (09:00-15:00 M-F)	2.4 | 1.9	24.1 | 24.4	Unknown	N/A	643 | 660
Weekend Daytime (07:00-19:00 S-U)	0.7 | 0.7	20.0 | 19.1	Unknown	N/A	612 | 641
Nighttime (20:00-04:00 M-U)	0.1 | 0.1	6.8 | 3.8	Unknown	N/A	202 | 108

Units are in average number of vehicles per hour per segment or detector, EB | WB

Table 3.11. US 14 (Madison) Total Vehicle Percentages, May 2016

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	0.1 | 0.1	4.2 | 2.5	Unknown
AM Peak (07:30-08:30 M-F)	0.1 | 0.1	3.6 | 2.2	Unknown
PM Rush (15:00-18:00 M-F)	0.1 | 0.1	2.6 | 3.2	Unknown
PM Peak (16:30-17:30 M-F)	0.1 | 0.1	2.6 | 3.1	Unknown
Weekday Daytime (09:00-15:00 M-F)	0.4 | 0.3	3.8 | 3.7	Unknown
Weekend Daytime (07:00-19:00 S-U)	0.1 | 0.1	3.3 | 3.0	Unknown
Nighttime (20:00-04:00 M-U)	0.1 | 0.1	3.4 | 3.5	Unknown

Units are in percent (number of vehicles per ATR count per segment per detector), EB | WB

Table 3.12. US 14 (Madison) Observation Percentages, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	99.6 | 100.0	38.6 | 63.4	N/A
AM Peak (07:30-08:30 M-F)	Unknown	100.0 | 100.0	36.7 | 61.5	N/A
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 100.0	53.2 | 46.5	N/A
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	50.5 | 43.6	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	100.0 | 100.0	45.5 | 52.7	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	99.7 | 100.0	17.5 | 21.4	N/A
Nighttime (22:00-04:00 M-U)	Unknown	83.6 | 67.5	6.2 | 6.9	N/A

Units are in percentage of segment time periods with at least one observation, EB | WB

Table 3.13. US 14 (Madison) Usable Travel Time Availability Percentages, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	100.0 | 100.0	35.6 | 71.6	N/A
AM Peak (07:30-08:30 M-F)	Unknown	100.0 | 100.0	34.1 | 70.1	N/A
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 100.0	56.8 | 50.1	N/A
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	54.2 | 45.8	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	100.0 | 100.0	45.8 | 57.4	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	100.0 | 100.0	13.7 | 21.9	N/A
Nighttime (22:00-04:00 M-U)	Unknown	83.9 | 68.1	4.2 | 6.1	N/A

Units are in percentage of travel times calculable for entire corridor for the entire month, EB | WB

3.3.4. Data Availability for County M (Rural Minor Arterial)

Table 3.14. County M Total Vehicle Counts, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	0.2 | 0.3	N/A	Unknown	N/A	N/A
AM Peak (07:30-08:30 M-F)	0.3 | 0.3	N/A	Unknown	N/A	N/A
PM Rush (15:00-18:00 M-F)	0.4 | 0.3	N/A	Unknown	N/A	N/A
PM Peak (16:30-17:30 M-F)	0.4 | 0.3	N/A	Unknown	N/A	N/A
Weekday Daytime (09:00-15:00 M-F)	0.4 | 0.4	N/A	Unknown	N/A	N/A
Weekend Daytime (07:00-19:00 S-U)	0.2 | 0.2	N/A	Unknown	N/A	N/A
Nighttime (20:00-04:00 M-U)	0.0 | 0.0	N/A	Unknown	N/A	N/A

Units are in average number of vehicles per hour per segment or detector, EB | WB

Table 3.15. County M Total Vehicle Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	N/A	N/A	Unknown
AM Peak (07:30-08:30 M-F)	N/A	N/A	Unknown
PM Rush (15:00-18:00 M-F)	N/A	N/A	Unknown
PM Peak (16:30-17:30 M-F)	N/A	N/A	Unknown
Weekday Daytime (09:00-15:00 M-F)	N/A	N/A	Unknown
Weekend Daytime (07:00-19:00 S-U)	N/A	N/A	Unknown
Nighttime (20:00-04:00 M-U)	N/A	N/A	Unknown

Units are in percent (number of vehicles per ATR count per segment per detector), EB | WB

Table 3.16. County M Observation Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	N/A	30.2 | 15.9	N/A
AM Peak (07:30-08:30 M-F)	Unknown	N/A	40.5 | 16.9	N/A
PM Rush (15:00-18:00 M-F)	Unknown	N/A	36.2 | 10.3	N/A
PM Peak (16:30-17:30 M-F)	Unknown	N/A	33.3 | 10.9	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	N/A	22.9 | 11.5	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	N/A	8.0 | 4.4	N/A
Nighttime (22:00-04:00 M-U)	Unknown	N/A	2.0 | 0.7	N/A

Units are in percentage of segment time periods with at least one observation, EB | WB

Table 3.17. County M Usable Travel Time Availability Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	N/A	30.2 | 1.2	N/A
AM Peak (07:30-08:30 M-F)	Unknown	N/A	40.5 | 1.6	N/A
PM Rush (15:00-18:00 M-F)	Unknown	N/A	36.2 | 0.5	N/A
PM Peak (16:30-17:30 M-F)	Unknown	N/A	33.3 | 0.8	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	N/A	22.9 | 0.6	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	N/A	8.0 | 0.7	N/A
Nighttime (22:00-04:00 M-U)	Unknown	N/A	2.0 | 0.1	N/A

Units are in percentage of travel times calculable for entire corridor for the entire month, EB | WB

Table 3.18. County M Total Vehicle Counts, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	0.2 | 0.5	N/A	Unknown	N/A	N/A
AM Peak (07:30-08:30 M-F)	0.2 | 0.6	N/A	Unknown	N/A	N/A
PM Rush (15:00-18:00 M-F)	0.4 | 0.3	N/A	Unknown	N/A	N/A
PM Peak (16:30-17:30 M-F)	0.5 | 0.4	N/A	Unknown	N/A	N/A
Weekday Daytime (09:00-15:00 M-F)	0.7 | 0.5	N/A	Unknown	N/A	N/A
Weekend Daytime (07:00-19:00 S-U)	0.2 | 0.2	N/A	Unknown	N/A	N/A
Nighttime (20:00-04:00 M-U)	0.0 | 0.0	N/A	Unknown	N/A	N/A

Units are in average number of vehicles per hour per segment or detector, EB | WB

Table 3.19. County M Total Vehicle Percentages, May 2016

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	N/A	N/A	Unknown
AM Peak (07:30-08:30 M-F)	N/A	N/A	Unknown
PM Rush (15:00-18:00 M-F)	N/A	N/A	Unknown
PM Peak (16:30-17:30 M-F)	N/A	N/A	Unknown
Weekday Daytime (09:00-15:00 M-F)	N/A	N/A	Unknown
Weekend Daytime (07:00-19:00 S-U)	N/A	N/A	Unknown
Nighttime (20:00-04:00 M-U)	N/A	N/A	Unknown

Units are in percent (number of vehicles per ATR count per segment per detector), EB | WB

Table 3.20. County M Observation Percentages, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	N/A	34.8 | 28.9	N/A
AM Peak (07:30-08:30 M-F)	Unknown	N/A	39.3 | 28.5	N/A
PM Rush (15:00-18:00 M-F)	Unknown	N/A	39.7 | 28.5	N/A
PM Peak (16:30-17:30 M-F)	Unknown	N/A	43.2 | 30.8	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	N/A	32.3 | 23.8	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	N/A	10.6 | 6.9	N/A
Nighttime (22:00-04:00 M-U)	Unknown	N/A	5.4 | 2.6	N/A

Units are in percentage of segment time periods with at least one observation, EB | WB

Table 3.21. County M Usable Travel Time Availability Percentages, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	N/A	33.3 | 25.0	N/A
AM Peak (07:30-08:30 M-F)	Unknown	N/A	39.4 | 23.9	N/A
PM Rush (15:00-18:00 M-F)	Unknown	N/A	40.0 | 23.9	N/A
PM Peak (16:30-17:30 M-F)	Unknown	N/A	45.5 | 26.9	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	N/A	28.7 | 17.6	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	N/A	6.7 | 4.0	N/A
Nighttime (22:00-04:00 M-U)	Unknown	N/A	4.0 | 1.4	N/A

Units are in percentage of travel times calculable for entire corridor for the entire month, EB | WB

3.3.5. Data Availability for US 14J (Suburban Principal Arterial)

Table 3.22. US 14 (Janesville) Total Vehicle Counts, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	22.9 | 36.3	17.9 | 31.0	Unknown	N/A	1206 | 2457
AM Peak (07:30-08:30 M-F)	25.4 | 39.1	18.4 | 32.8	Unknown	N/A	1219 | 2713
PM Rush (15:00-18:00 M-F)	47.8 | 42.3	33.4 | 25.7	Unknown	N/A	2709 | 1571
PM Peak (16:30-17:30 M-F)	49.9 | 43.8	33.3 | 25.5	Unknown	N/A	2979 | 1579
Weekday Daytime (09:00-15:00 M-F)	33.0 | 37.9	23.3 | 24.8	Unknown	N/A	1493 | 1424
Weekend Daytime (07:00-19:00 S-U)	26.4 | 29.0	15.6 | 17.9	Unknown	N/A	1095 | 1074
Nighttime (20:00-04:00 M-U)	13.5 | 14.7	6.9 | 6.3	Unknown	N/A	352 | 284

Units are in average number of vehicles per hour per segment or detector, EB | WB

Table 3.23. US 14 (Janesville) Total Vehicle Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	0.2 | 0.1	2.3 | 2.3	Unknown
AM Peak (07:30-08:30 M-F)	0.2 | 0.1	2.7 | 2.5	Unknown
PM Rush (15:00-18:00 M-F)	0.1 | 0.1	1.9 | 1.8	Unknown
PM Peak (16:30-17:30 M-F)	0.1 | 0.2	1.7 | 1.7	Unknown
Weekday Daytime (09:00-15:00 M-F)	0.4 | 0.4	2.6 | 2.9	Unknown
Weekend Daytime (07:00-19:00 S-U)	0.2 | 0.1	1.9 | 2.1	Unknown
Nighttime (20:00-04:00 M-U)	0.1 | 0.1	2.0 | 2.6	Unknown

Units are in percent (number of vehicles per ATR count per segment per detector), EB | WB

Table 3.24. US 14 (Janesville) Observation Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	96.4 | 95.2	34.6 | 39.4	N/A
AM Peak (07:30-08:30 M-F)	Unknown	97.6 | 97.6	33.0 | 45.0	N/A
PM Rush (15:00-18:00 M-F)	Unknown	99.2 | 96.0	33.5 | 34.9	N/A
PM Peak (16:30-17:30 M-F)	Unknown	97.6 | 97.6	31.1 | 31.0	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	98.8 | 99.6	36.1 | 42.1	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	91.3 | 95.8	15.9 | 18.0	N/A
Nighttime (22:00-04:00 M-U)	Unknown	47.8 | 52.4	5.1 | 6.5	N/A

Units are in percentage of segment time periods with at least one observation, EB | WB

Table 3.25. US 14 (Janesville) Usable Travel Time Availability Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	96.4 | 95.2	12.9 | 23.2	N/A
AM Peak (07:30-08:30 M-F)	Unknown	97.6 | 97.6	13.5 | 31.0	N/A
PM Rush (15:00-18:00 M-F)	Unknown	99.2 | 96.0	11.1 | 18.3	N/A
PM Peak (16:30-17:30 M-F)	Unknown	97.6 | 97.6	9.9 | 13.9	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	98.8 | 99.6	13.6 | 26.8	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	91.3 | 95.8	2.8 | 6.4	N/A
Nighttime (22:00-04:00 M-U)	Unknown	47.8 | 52.4	0.3 | 1.1	N/A

Units are in percentage of travel times calculable for entire corridor for the entire month, EB | WB

3.3.6. Data Availability for WIS 73 (Rural Minor Arterial)

Table 3.26. WIS 73 Total Vehicle Counts, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	0.2 | 0.3	N/A	Unknown	57 | 60	N/A
AM Peak (07:30-08:30 M-F)	0.1 | 0.2	N/A	Unknown	59 | 59	N/A
PM Rush (15:00-18:00 M-F)	0.1 | 0.1	N/A	Unknown	73 | 75	N/A
PM Peak (16:30-17:30 M-F)	0.2 | 0.2	N/A	Unknown	76 | 74	N/A
Weekday Daytime (09:00-15:00 M-F)	0.2 | 0.2	N/A	Unknown	57 | 53	N/A
Weekend Daytime (07:00-19:00 S-U)	0.2 | 0.1	N/A	Unknown	53 | 53	N/A
Nighttime (20:00-04:00 M-U)	0.0 | 0.0	N/A	Unknown	15 | 13	N/A

Units are in average number of vehicles per hour per segment or detector, NB | SB

Table 3.27. WIS 73 Total Vehicle Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	0.3 | 0.4	N/A	Unknown
AM Peak (07:30-08:30 M-F)	0.2 | 0.3	N/A	Unknown
PM Rush (15:00-18:00 M-F)	0.2 | 0.2	N/A	Unknown
PM Peak (16:30-17:30 M-F)	0.3 | 0.2	N/A	Unknown
Weekday Daytime (09:00-15:00 M-F)	0.4 | 0.3	N/A	Unknown
Weekend Daytime (07:00-19:00 S-U)	0.4 | 0.2	N/A	Unknown
Nighttime (20:00-04:00 M-U)	8.4 | 8.1	N/A	Unknown

Units are in percent (number of vehicles per microwave count per segment per detector), NB | SB

Table 3.28. WIS 73 Observation Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	N/A	7.5 | 9.1	98.8 | 98.2
AM Peak (07:30-08:30 M-F)	Unknown	N/A	7.1 | 8.7	98.8 | 97.6
PM Rush (15:00-18:00 M-F)	Unknown	N/A	7.1 | 12.7	99.2 | 99.2
PM Peak (16:30-17:30 M-F)	Unknown	N/A	5.6 | 11.9	100.0 | 100.0
Weekday Daytime (09:00-15:00 M-F)	Unknown	N/A	8.0 | 14.4	99.8 | 98.4
Weekend Daytime (06:00-18:00 S-U)	Unknown	N/A	4.2 | 6.9	99.8 | 100.0
Nighttime (22:00-04:00 M-U)	Unknown	N/A	1.2 | 6.3	78.9 | 79.3

Units are in percentage of segment time periods with at least one observation, NB | SB

Table 3.29. WIS 73 Usable Travel Time Availability Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	N/A	7.5 | 9.1	98.8 | 98.2
AM Peak (07:30-08:30 M-F)	Unknown	N/A	7.1 | 8.7	98.8 | 97.6
PM Rush (15:00-18:00 M-F)	Unknown	N/A	7.1 | 12.7	99.2 | 99.2
PM Peak (16:30-17:30 M-F)	Unknown	N/A	5.6 | 11.9	100.0 | 100.0
Weekday Daytime (09:00-15:00 M-F)	Unknown	N/A	8.0 | 14.4	99.8 | 98.4
Weekend Daytime (06:00-18:00 S-U)	Unknown	N/A	4.2 | 6.9	99.8 | 100.0
Nighttime (22:00-04:00 M-U)	Unknown	N/A	1.2 | 6.3	78.9 | 79.3

Units are in percentage of travel times calculable for entire corridor for the entire month, NB | SB

Table 3.30. WIS 73 Total Vehicle Counts, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	0.1 | 0.2	N/A	Unknown	62 | 70	N/A
AM Peak (07:30-08:30 M-F)	0.2 | 0.2	N/A	Unknown	62 | 74	N/A
PM Rush (15:00-18:00 M-F)	0.3 | 0.3	N/A	Unknown	84 | 95	N/A
PM Peak (16:30-17:30 M-F)	0.4 | 0.2	N/A	Unknown	89 | 105	N/A
Weekday Daytime (09:00-15:00 M-F)	0.6 | 0.6	N/A	Unknown	60 | 60	N/A
Weekend Daytime (07:00-19:00 S-U)	0.2 | 0.2	N/A	Unknown	61 | 59	N/A
Nighttime (20:00-04:00 M-U)	0.0 | 0.0	N/A	Unknown	17 | 12	N/A

Units are in average number of vehicles per hour per segment or detector, NB | SB

Table 3.31. WIS 73 Total Vehicle Percentages, May 2016

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	0.2 | 0.3	N/A	Unknown
AM Peak (07:30-08:30 M-F)	0.3 | 0.2	N/A	Unknown
PM Rush (15:00-18:00 M-F)	0.4 | 0.3	N/A	Unknown
PM Peak (16:30-17:30 M-F)	0.4 | 0.2	N/A	Unknown
Weekday Daytime (09:00-15:00 M-F)	1.0 | 1.0	N/A	Unknown
Weekend Daytime (07:00-19:00 S-U)	0.4 | 0.4	N/A	Unknown
Nighttime (20:00-04:00 M-U)	22.6 | 28.4	N/A	Unknown

Units are in percent (number of vehicles per microwave count per segment per detector), NB | SB

Table 3.32. WIS 73 Observation Percentages, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	N/A	10.4 | 13.3	98.3 | 98.3
AM Peak (07:30-08:30 M-F)	Unknown	N/A	8.0 | 12.1	98.9 | 98.9
PM Rush (15:00-18:00 M-F)	Unknown	N/A	6.8 | 24.2	99.6 | 99.6
PM Peak (16:30-17:30 M-F)	Unknown	N/A	6.1 | 26.5	100.0 | 100.0
Weekday Daytime (09:00-15:00 M-F)	Unknown	N/A	9.3 | 16.6	95.5 | 95.5
Weekend Daytime (06:00-18:00 S-U)	Unknown	N/A	3.3 | 8.6	100.0 | 100.0
Nighttime (22:00-04:00 M-U)	Unknown	N/A	0.9 | 5.0	83.6 | 78.6

Units are in percentage of segment time periods with at least one observation, NB | SB

Table 3.33. WIS 73 Usable Travel Time Availability Percentages, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	N/A	10.4 | 13.3	98.3 | 98.3
AM Peak (07:30-08:30 M-F)	Unknown	N/A	8.0 | 12.1	98.9 | 98.9
PM Rush (15:00-18:00 M-F)	Unknown	N/A	6.8 | 24.2	99.6 | 99.6
PM Peak (16:30-17:30 M-F)	Unknown	N/A	6.1 | 26.5	100.0 | 100.0
Weekday Daytime (09:00-15:00 M-F)	Unknown	N/A	9.3 | 16.6	95.5 | 95.5
Weekend Daytime (06:00-18:00 S-U)	Unknown	N/A	3.3 | 8.6	100.0 | 100.0
Nighttime (22:00-04:00 M-U)	Unknown	N/A	0.9 | 5.0	83.6 | 78.6

Units are in percentage of travel times calculable for entire corridor for the entire month, NB | SB

3.3.7. Data Availability for US 151 (Urban Principal Arterial)

Table 3.34. US 151 Total Vehicle Counts, July 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	22.8 | 36.3	17.9 | 31.0	Unknown	N/A	1206 | 2457
AM Peak (07:30-08:30 M-F)	25.4 | 39.1	18.4 | 32.8	Unknown	N/A	1219 | 2713
PM Rush (15:00-18:00 M-F)	47.8 | 42.3	33.4 | 25.7	Unknown	N/A	2709 | 1571
PM Peak (16:30-17:30 M-F)	49.9 | 43.8	33.3 | 25.5	Unknown	N/A	2979 | 1579
Weekday Daytime (09:00-15:00 M-F)	69.3 | 79.5	23.3 | 24.8	Unknown	N/A	1493 | 1424
Weekend Daytime (07:00-19:00 S-U)	28.4 | 31.5	16.5 | 19.1	Unknown	N/A	1165 | 1128
Nighttime (20:00-04:00 M-U)	10.1 | 11.0	9.0 | 8.4	Unknown	N/A	515 | 423

Units are in average number of vehicles per hour per segment or detector, NB | SB

Table 3.35. US 151 Total Vehicle Percentages, July 2016

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	1.9 | 1.5	1.5 | 1.3	Unknown
AM Peak (07:30-08:30 M-F)	2.1 | 1.4	1.5 | 1.2	Unknown
PM Rush (15:00-18:00 M-F)	1.8 | 2.7	1.2 | 1.6	Unknown
PM Peak (16:30-17:30 M-F)	1.7 | 2.8	1.1 | 1.6	Unknown
Weekday Daytime (09:00-15:00 M-F)	4.6 | 5.6	1.6 | 1.7	Unknown
Weekend Daytime (07:00-19:00 S-U)	2.4 | 2.8	1.4 | 1.7	Unknown
Nighttime (20:00-04:00 M-U)	2.0 | 2.6	1.7 | 2.0	Unknown

Units are in percent (number of vehicles per ATR count per segment per detector), NB | SB

Table 3.36. US 151 Observation Percentages, July 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	99.4 | 98.2	57.7 | 72.3	N/A
AM Peak (07:30-08:30 M-F)	Unknown	98.8 | 98.8	60.1 | 73.3	N/A
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 100.0	67.8 | 54.1	N/A
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	64.6 | 54.2	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	100.0 | 100.0	70.2 | 71.0	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	99.6 | 100.0	33.4 | 36.6	N/A
Nighttime (22:00-04:00 M-U)	Unknown	91.8 | 90.4	13.4 | 13.1	N/A

Units are in percentage of segment time periods with at least one observation, NB | SB

Table 3.37. US 151 Usable Travel Time Availability Percentages, July 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	98.8 | 97.6	53.8 | 76.0	N/A
AM Peak (07:30-08:30 M-F)	Unknown	97.6 | 97.6	59.9 | 77.4	N/A
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 100.0	66.5 | 46.2	N/A
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	61.9 | 44.4	N/A
Weekday Daytime (09:00-15:00 M-F)	Unknown	100.0 | 100.0	71.6 | 73.1	N/A
Weekend Daytime (06:00-18:00 S-U)	Unknown	99.2 | 100.0	21.3 | 23.9	N/A
Nighttime (22:00-04:00 M-U)	Unknown	86.3 | 84.3	5.3 | 5.3	N/A

Units are in percentage of travel times calculable for entire corridor for the entire month, NB | SB

3.3.8. Data Availability for I-39/90 (Rural Freeway)

Table 3.38. I-39/90 Total Vehicle Counts, July 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	5.9 | 3.9	140.5 | 119.8	Unknown	1691 | 1522	2252 | 1775
AM Peak (07:30-08:30 M-F)	5.1 | 4.0	138.7 | 121.8	Unknown	1796 | 1524	2394 | 1848
PM Rush (15:00-18:00 M-F)	6.6 | 6.4	175.6 | 180.3	Unknown	1775 | 1774	2575 | 2751
PM Peak (16:30-17:30 M-F)	5.7 | 6.4	173.1 | 184.7	Unknown	1805 | 1872	2654 | 2925
Weekday Daytime (09:00-15:00 M-F)	19.0 | 15.5	176.4 | 169.2	Unknown	1619 | 1491	2342 | 2173
Weekend Daytime (07:00-19:00 S-U)	6.2 | 6.3	126.1 | 135.6	Unknown	1499 | 1550	2136 | 2297
Nighttime (20:00-04:00 M-U)	1.7 | 1.7	63.7 | 60.0	Unknown	461 | 474	606 | 641

Units are in average number of vehicles per hour per segment or detector, NB | SB

Table 3.39. I-39/90 Total Vehicle Percentages, July 2015

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	0.3 | 0.2	7.1 | 7.3	Unknown
AM Peak (07:30-08:30 M-F)	0.2 | 0.2	6.6 | 7.2	Unknown
PM Rush (15:00-18:00 M-F)	0.3 | 0.3	8.1 | 8.0	Unknown
PM Peak (16:30-17:30 M-F)	0.3 | 0.3	7.8 | 7.7	Unknown
Weekday Daytime (09:00-15:00 M-F)	1.0 | 0.8	8.9 | 9.2	Unknown
Weekend Daytime (07:00-19:00 S-U)	0.3 | 0.3	6.9 | 7.0	Unknown
Nighttime (20:00-04:00 M-U)	0.3 | 0.3	11.9 | 11.9	Unknown

Units are in percent (num. of veh. per avg. ATR/µwave/loop count per seg. per detector), NB | SB

Table 3.40. I-39/90 Observation Percentages, July 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	100.0 | 100.0	95.4 | 94.8	76.3 | 86.3
AM Peak (07:30-08:30 M-F)	Unknown	100.0 | 100.0	95.4 | 95.2	76.3 | 86.5
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 99.9	96.1 | 96.9	70.5 | 79.6
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	95.7 | 96.7	70.0 | 79.0
Weekday Daytime (09:00-15:00 M-F)	Unknown	100.0 | 100.0	96.1 | 96.7	74.9 | 84.9
Weekend Daytime (06:00-18:00 S-U)	Unknown	100.0 | 99.9	94.6 | 94.8	76.4 | 86.6
Nighttime (22:00-04:00 M-U)	Unknown	99.8 | 99.9	87.7 | 85	71.3 | 80.6

Units are in percentage of segment time periods with at least one observation, NB | SB

Table 3.41. I-39/90 Usable Travel Time Availability Percentages, July 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	100.0 | 100.0	100.0 | 100.0	100.0 | 100.0
AM Peak (07:30-08:30 M-F)	Unknown	100.0 | 100.0	100.0 | 100.0	100.0 | 100.0
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 100.0	100.0 | 100.0	92.0 | 92.0
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	100.0 | 100.0	91.3 | 91.3
Weekday Daytime (09:00-15:00 M-F)	Unknown	100.0 | 100.0	100.0 | 100.0	98.0 | 98.0
Weekend Daytime (06:00-18:00 S-U)	Unknown	100.0 | 100.0	100.0 | 99.7	98.4 | 98.4
Nighttime (22:00-04:00 M-U)	Unknown	100.0 | 100.0	95.3 | 90.6	86.9 | 96.0

Units are in percentage of travel times calculable for entire corridor for the entire month, NB | SB

Table 3.42. I-39/90 Total Vehicle Counts, July 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	82.2 | 61.4	163.7 | 138.5	Unknown	1813 | 1500	2233 | 1763
AM Peak (07:30-08:30 M-F)	83.8 | 61.8	164.9 | 136.8	Unknown	1936 | 1490	2353 | 1826
PM Rush (15:00-18:00 M-F)	124.1 | 120.6	190.6 | 209.6	Unknown	2066 | 2124	2489 | 2778
PM Peak (16:30-17:30 M-F)	124.1 | 122.1	185.5 | 209.5	Unknown	2121 | 2247	2551 | 2913
Weekday Daytime (09:00-15:00 M-F)	263.5 | 233.8	190.8 | 199.0	Unknown	1817 | 1714	2289 | 2232
Weekend Daytime (07:00-19:00 S-U)	131.1 | 121.6	143.2 | 146.0	Unknown	1756 | 1682	2249 | 2305
Nighttime (20:00-04:00 M-U)	33.3 | 29.9	71.5 | 67.5	Unknown	516 | 501	624 | 639

Units are in average number of vehicles per hour per segment or detector, NB | SB

Table 3.43. I-39/90 Total Vehicle Percentages, July 2016

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	4.1 | 3.8	8.1 | 8.5	Unknown
AM Peak (07:30-08:30 M-F)	3.9 | 3.7	7.7 | 8.3	Unknown
PM Rush (15:00-18:00 M-F)	5.4 | 4.9	8.4 | 8.6	Unknown
PM Peak (16:30-17:30 M-F)	5.3 | 4.7	7.9 | 8.1	Unknown
Weekday Daytime (09:00-15:00 M-F)	12.8 | 11.9	9.3 | 10.1	Unknown
Weekend Daytime (07:00-19:00 S-U)	6.5 | 6.1	7.1 | 7.3	Unknown
Nighttime (20:00-04:00 M-U)	5.8 | 5.8	12.5 | 13.2	Unknown

Units are in percent (num. of veh. per avg. ATR/µwave/loop count per seg. per detector), NB | SB

Table 3.44. I-39/90 Observation Percentages, July 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	100.0 | 100.0	95 | 95.4	86.4 | 91.6
AM Peak (07:30-08:30 M-F)	Unknown	100.0 | 100.0	95 | 95.3	86.5 | 91.7
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 100.0	95.4 | 97.1	84.1 | 91.7
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	95.2 | 96.9	84.2 | 92.0
Weekday Daytime (09:00-15:00 M-F)	Unknown	99.8 | 100.0	95.6 | 96.8	84.3 | 91.6
Weekend Daytime (06:00-18:00 S-U)	Unknown	99.9 | 100.0	94.9 | 95.7	86.2 | 90.5
Nighttime (22:00-04:00 M-U)	Unknown	99.9 | 99.8	89.3 | 87.1	86.3 | 87.4

Units are in percentage of segment time periods with at least one observation, NB | SB

Table 3.45. I-39/90 Usable Travel Time Availability Percentages, July 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	100.0 | 100.0	100.0 | 99.8	100.0 | 100.0
AM Peak (07:30-08:30 M-F)	Unknown	100.0 | 100.0	100.0 | 99.6	100.0 | 100.0
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 100.0	100.0 | 100.0	100.0 | 100.0
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	100.0 | 100.0	100.0 | 100.0
Weekday Daytime (09:00-15:00 M-F)	Unknown	100.0 | 100.0	100.0 | 100.0	99.8 | 100.0
Weekend Daytime (06:00-18:00 S-U)	Unknown	100.0 | 100.0	100.0 | 100.0	99.8 | 99.8
Nighttime (22:00-04:00 M-U)	Unknown	100.0 | 100.0	97.2 | 92.5	100.0 | 100.0

Units are in percentage of travel times calculable for entire corridor for the entire month, NB | SB

3.3.9. Data Availability for US 12 (Urban Freeway)

Table 3.46. US 12 Total Vehicle Counts, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	3.1 | 4.3	114.1 | 122.1	Unknown	1843 | 2310	2840 | 2822
AM Peak (07:30-08:30 M-F)	3.2 | 4.3	119.7 | 118.8	Unknown	1983 | 2317	3163 | 3124
PM Rush (15:00-18:00 M-F)	4.7 | 3.6	126.3 | 118.9	Unknown	2211 | 2114	3118 | 2977
PM Peak (16:30-17:30 M-F)	5.1 | 3.3	125.1 | 122.2	Unknown	2253 | 2240	3267 | 3208
Weekday Daytime (09:00-15:00 M-F)	7.9 | 8.5	112.8 | 110.0	Unknown	1555 | 1672	2149 | 2102
Weekend Daytime (07:00-19:00 S-U)	3.6 | 3.4	78.1 | 76.4	Unknown	1398 | 1478	1877 | 1805
Nighttime (20:00-04:00 M-U)	0.6 | 0.6	23.2 | 24.8	Unknown	387 | 411	470 | 462

Units are in average number of vehicles per hour per segment or detector, EB | WB

Table 3.47. US 12 Total Vehicle Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	0.1 | 0.2	5.2 | 4.7	Unknown
AM Peak (07:30-08:30 M-F)	0.1 | 0.2	5.0 | 4.3	Unknown
PM Rush (15:00-18:00 M-F)	0.2 | 0.1	5.2 | 4.6	Unknown
PM Peak (16:30-17:30 M-F)	0.2 | 0.1	5.0 | 4.4	Unknown
Weekday Daytime (09:00-15:00 M-F)	0.5 | 0.4	6.7 | 5.6	Unknown
Weekend Daytime (07:00-19:00 S-U)	0.2 | 0.2	5.2 | 4.5	Unknown
Nighttime (20:00-04:00 M-U)	0.2 | 0.1	6.0 | 5.4	Unknown

Units are in percent (num. of veh. per avg. ATR/µwave/loop count per seg. per detector), EB | WB

Table 3.48. US 12 Observation Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	100.0 | 100.0	76.0 | 76.4	60.8 | 64.0
AM Peak (07:30-08:30 M-F)	Unknown	100.0 | 100.0	77.7 | 77.2	60.3 | 63.5
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 99.9	75.3 | 73.7	60.7 | 64.2
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	72.6 | 71.4	60.8 | 64.5
Weekday Daytime (09:00-15:00 M-F)	Unknown	99.8 | 99.8	79.7 | 76.9	60.0 | 63.7
Weekend Daytime (06:00-18:00 S-U)	Unknown	99.9 | 100.0	43.8 | 43.9	60.2 | 64.8
Nighttime (22:00-04:00 M-U)	Unknown	97.5 | 97.7	23.9 | 23.5	57.0 | 60.2

Units are in percentage of segment time periods with at least one observation, EB | WB

Table 3.49. US 12 Usable Travel Time Availability Percentages, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	100.0 | 100.0	81.5 | 81.7	0.0 | 33.3
AM Peak (07:30-08:30 M-F)	Unknown	100.0 | 100.0	84.1 | 84.1	0.0 | 31.0
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 100.0	78.6 | 71.6	0.0 | 34.9
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	73.0 | 69.8	0.0 | 31.0
Weekday Daytime (09:00-15:00 M-F)	Unknown	100.0 | 100.0	87.4 | 81.7	0.0 | 26.6
Weekend Daytime (06:00-18:00 S-U)	Unknown	100.0 | 100.0	13.7 | 10.6	0.0 | 29.0
Nighttime (22:00-04:00 M-U)	Unknown	99.8 | 99.8	1.8 | 0.9	0.0 | 7.0

Units are in percentage of travel times calculable for entire corridor for the entire month, EB | WB

Table 3.50. US 12 Total Vehicle Counts, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop	ATR
AM Rush (07:00-09:00 M-F)	3.8 | 4.3	127.7 | 146.2	Unknown	2213 | 2151	3042 | 2846
AM Peak (07:30-08:30 M-F)	4.3 | 4.2	130.8 | 143.8	Unknown	2380 | 2130	3375 | 3151
PM Rush (15:00-18:00 M-F)	3.9 | 3.9	140.4 | 135.8	Unknown	2535 | 2138	3156 | 3065
PM Peak (16:30-17:30 M-F)	3.8 | 3.5	137.3 | 139.2	Unknown	2591 | 2261	3310 | 3307
Weekday Daytime (09:00-15:00 M-F)	9.1 | 9.9	128.7 | 133.8	Unknown	1739 | 1659	2249 | 2198
Weekend Daytime (07:00-19:00 S-U)	3.1 | 3.3	91.2 | 94.6	Unknown	1591 | 1467	1989 | 1914
Nighttime (20:00-04:00 M-U)	0.6 | 0.6	29.1 | 31.0	Unknown	456 | 428	490 | 477

Units are in average number of vehicles per hour per segment or detector, EB | WB

Table 3.51. US 12 Total Vehicle Percentages, May 2016

Time Period	TT – CTT	BT	NPMRDS
AM Rush (07:00-09:00 M-F)	0.2 | 0.2	6.7 | 6.2	Unknown
AM Peak (07:30-08:30 M-F)	0.2 | 0.2	6.2 | 5.8	Unknown
PM Rush (15:00-18:00 M-F)	0.2 | 0.2	7.1 | 5.4	Unknown
PM Peak (16:30-17:30 M-F)	0.2 | 0.1	6.6 | 5.2	Unknown
Weekday Daytime (09:00-15:00 M-F)	0.7 | 0.5	9.2 | 7.2	Unknown
Weekend Daytime (07:00-19:00 S-U)	0.3 | 0.2	7.4 | 5.9	Unknown
Nighttime (20:00-04:00 M-U)	0.2 | 0.1	9.0 | 7.0	Unknown

Units are in percent (num. of veh. per avg. ATR/µwave/loop count per seg. per detector), EB | WB

Table 3.52. US 12 Observation Percentages, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	96.0 | 99.9	82.5 | 81.8	69.0 | 67.9
AM Peak (07:30-08:30 M-F)	Unknown	96.0 | 100.0	82.8 | 82.3	69.5 | 68.5
PM Rush (15:00-18:00 M-F)	Unknown	96.2 | 99.8	79.6 | 77.8	70.6 | 70.2
PM Peak (16:30-17:30 M-F)	Unknown	96.5 | 100.0	77.7 | 75.5	71.0 | 70.4
Weekday Daytime (09:00-15:00 M-F)	Unknown	95.9 | 100.0	83.4 | 82.2	67.1 | 66.6
Weekend Daytime (06:00-18:00 S-U)	Unknown	95.1 | 100.0	51.8 | 49.5	67.7 | 66.6
Nighttime (22:00-04:00 M-U)	Unknown	94.9 | 98.8	26.9 | 25.8	67.9 | 66.8

Units are in percentage of segment time periods with at least one observation, EB | WB

Table 3.53. US 12 Usable Travel Time Availability Percentages, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	Unknown	100.0 | 100.0	90.9 | 92.0	87.5 | 93.2
AM Peak (07:30-08:30 M-F)	Unknown	100.0 | 100.0	90.2 | 92.8	86.4 | 94.3
PM Rush (15:00-18:00 M-F)	Unknown	100.0 | 100.0	86.4 | 79.5	92.4 | 99.6
PM Peak (16:30-17:30 M-F)	Unknown	100.0 | 100.0	86.0 | 74.2	90.9 | 100.0
Weekday Daytime (09:00-15:00 M-F)	Unknown	100.0 | 100.0	93.6 | 92.5	84.3 | 91.1
Weekend Daytime (06:00-18:00 S-U)	Unknown	100.0 | 100.0	25.7 | 19.3	76.9 | 88.9
Nighttime (22:00-04:00 M-U)	Unknown	100.0 | 100.0	2.9 | 1.2	77.9 | 78.9

Units are in percentage of travel times calculable for entire corridor for the entire month, EB | WB

3.4. T3E Interactive Online Map

An interactive web map (http://transportal.cee.wisc.edu/gis/webmaps/t3e) has been created to provide a visual representation of data source availability.

All routes are displayed on the map, similar to the original data availability map provided in the Analysis Plan. Four drop down menus are displayed with the following options.

- Data Type
    - TomTom CTT
    - Bluetooth
    - NPMRDS
    - VSPOC (µWave/Loop)
    - ATR

- Year
    - 2015
    - 2016

- Time Period
    - AM Rush
    - AM Peak
    - PM Rush
    - PM Peak
    - Weekday Daytime
    - Weekend Daytime
    - Nighttime

- Display Method
    - Total Vehicle Count (linear scale dependent on route)
    - Total Vehicle Percentage (linear scale from red to green 0 to 100)
    - Observation Percentage (linear scale from red to green 0 to 100)
    - Travel Time Availability Percentage (linear scale from red to green 0 to 100)
    - Average Speed (linear scale dependent on route)
    - Average Travel Time (linear scale dependent on route)

Images showing the map application are shown in Figures 3.2 and 3.3. Figure 3.2 shows an overall view of the project area and Figure 3.3 shows a detailed view of one of the route segments.

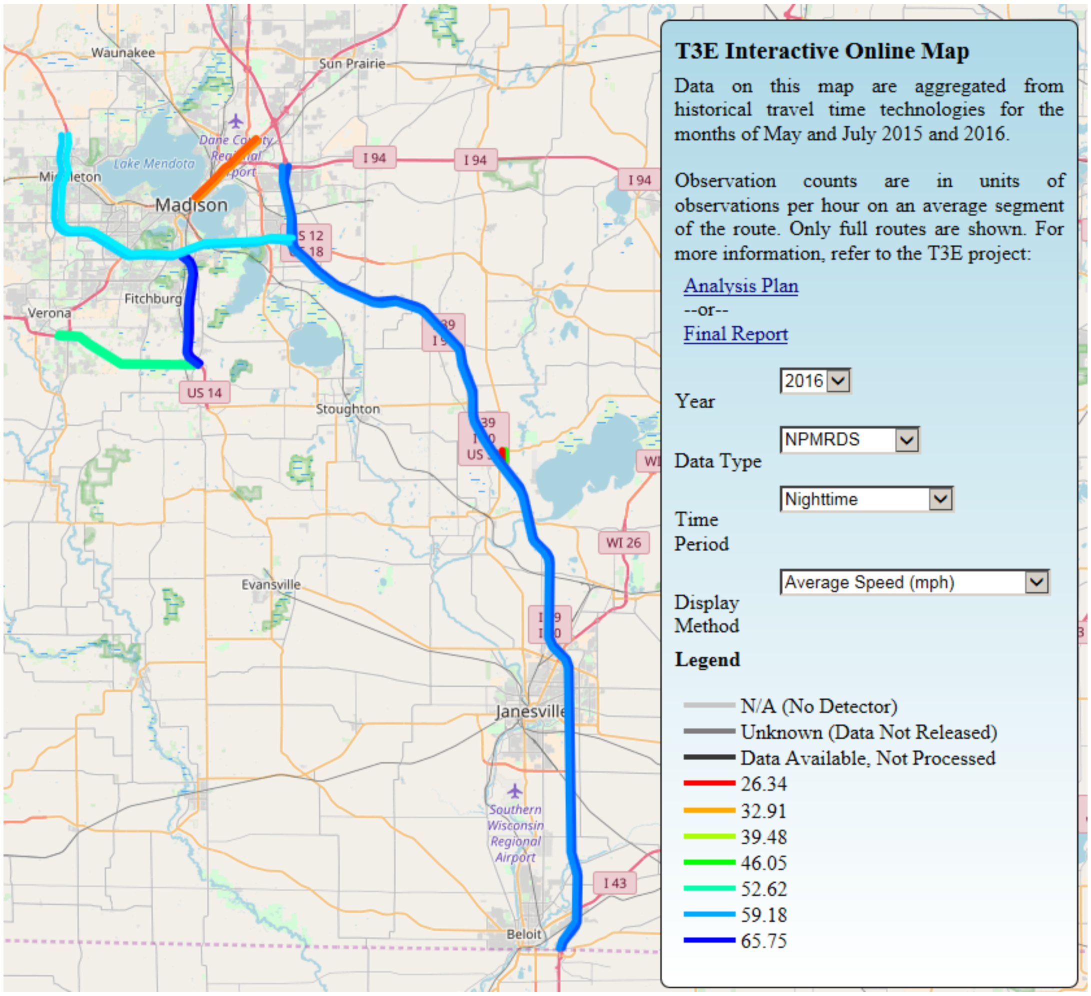


Figure 3.2. T3E Interactive Online Map Application – Full Study Area

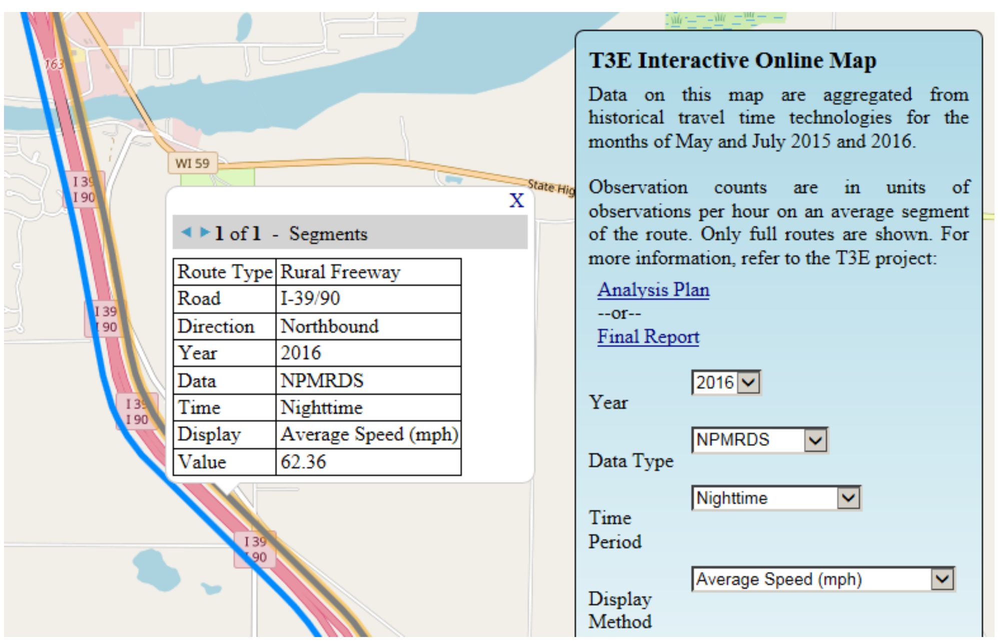


Figure 3.3. T3E Interactive Online Map Application – Detailed View of a Route Segment

The T3E Interactive Online Map provides a quick way to look at the data from this project. It should be noted that the data on the map is historical and is not updated or real-time. When first logging in to the web map, the user will see the entire study area along with the information window which includes drop down menus, instructions, and the legend.

The user selects the data type, time period, and year of interest along with the display method. The display method contains all four data availability measures along with average travel time and average travel speed. Once the entries are selected, all routes are updated showing the data for the selection.

The user can then click on a route by direction on the interactive map to display a pop-up window. This window shows the following information for the entire route in that direction:

- Route type (e.g., “Rural Freeway”)
- Road (e.g., “I-39/90”)
- Direction (e.g., “Northbound”)
- Year (e.g., “2016”)
- Data (e.g., “TomTom CTT”)
- Time (e.g., “AM Rush”)
- Display (e.g., “Observation Percentages (%)”)
- Value (e.g., “95.70”)

From here, the user can click on another route, change parameters in the drop down menu, print the map, or exit the program.

4. Travel Times and Analysis

This section includes all travel times, speeds, and statistical analyses for the project. Section 4.1 gives an overview of the travel time and speed calculations used for this project. Section 4.2 reports on findings from the travel time analysis and includes all travel time and speed tables and graphs. Section 4.3 includes additional granulized travel time and speed analysis. Section 4.4 reports on the statistical analyses of the travel times and speeds.

4.1 Travel Time Overview

The comparison of travel times follows the methodology described in the Analysis Plan, including the date ranges identified for each of the eight corridors and the statistics described in the plan and in more detail in the Literature Review. Travel times are presented in tandem with travel speeds in this report. Detail on each of these is outlined below.

Average travel times. This value is an average of the travel times on each segment of the route over each time period during the time interval. Five-minute or 15-minute time intervals are used depending on the detection type. Travel times for all detection types adhere to the 2/3 threshold rule, in that travel times are not calculated unless the time period has 2/3 of segments reporting available data. Because the total route distances vary, the actual route distance between intersections/interchanges for the entire route, as outlined in Table 1.2, is used. This is done by normalizing travel times from detector distance to full route distance, which allows for direct comparison of travel times between detection types.

Average travel speeds. This value is an average of the speeds on each segment of the route over each time period during the time interval. These are calculated using the same methodology as the average travel times listed above.

Table 4.1 shows base data which can be used to compare the travel times and speeds presented in the tables in Section 4.2. This table includes each route with its total segment distance, speed limit and travel time at the posted speed limit. In some cases, speed limits on the segments changed during the analysis period, so both values are shown.

Table 4.1. Route Speed Limits, Lengths, and Typical Travel Times

Route	Segment Distance (mi.)	Speed Limit, 2015 (mi/hr)	Travel Time at Speed Limit, 2015 (min.)	Speed Limit, 2016 (mi/hr)	Travel Time at Speed Limit, 2016 (min.)
US 12/18	10.6	55	11.6	55	11.6
US 14 (M)	6.3	65	5.8	70	5.4
County M	7.8	55	8.5	55	8.5
US 14 (J)	9.4	55	10.3	55	10.3
WIS 73	0.8	55	0.9	55	0.9
US 151	4.6	35	7.9	35	7.9
I-39/90	49.5	65	45.7	70	42.4
US 12	17.7	55	19.3	55	19.3

4.2 Travel Time and Travel Speed Tables, Graphs, and Discussion

Sections 4.2.1 through 4.2.8 include travel time tables and travel speed tables and graphs for each route. The graphs included in these sections give a visual representation of the data, with the speed limit for the route shown as a solid line allowing for easier average travel speed comparison.

Key findings and notes based on table and graph values are listed below with reference to specific tables, graphs, or values when relevant.

Most detection types provide reasonable travel times.

In general, most detection types on most routes provide reasonably accurate travel times and speeds on the average.

The rural principal arterial shows similar travel times across all time intervals.

Average travel times for US 12/18 to the east of Madison, a rural principal arterial shown in Section 4.2.1, do not vary much among detection types or time periods, which is to be expected on a rural route that consistently operates above breakdown speeds. In fact, all speeds are within 5 mi/hr of each other, with most being even closer due to one NPMRDS outlier of 60.3 mi/hr occurring at nighttime. This is likely due to the extremely low (0.2%) usable travel time percentage during this time interval. It should also be noted that TomTom CTT travel times seem reasonable despite the fact that they are only picking up a fraction of one percent of vehicles on the route during most time periods.

The suburban freeway shows expected rush period travel times.

For US 14 to the south of Madison, a suburban freeway shown in Section 4.2.2, travel times vary slightly based on time period, with the AM rush periods heading into Madison and PM rush periods heading out of Madison being slightly slower than other times. All three detection types on this segment perform similarly. It should be noted that NPMRDS speeds are the fastest on average and Bluetooth speeds seem to be the slowest on average, however these differences are small. Also of note are that TomTom travel speeds seem to be much slower in 2016 than 2015 for this route, despite the 5 mi/hr speed limit increase on the route. This could be attributable to a variety of reasons, but further study would need to be done to determine the cause.

The rural minor arterial shows slower speeds than expected.

Speeds on County M (Section 4.2.3) seem slower than would be expected on a rural minor arterial with low AADT. However, there is one signalized intersection and one four-way stop intersection on the route, so this could be responsible for some of the slower than posted speeds seen on the entire route. This is likely the case as both data sets are probe data sources which monitor vehicles across the entire route relatively evenly.

The suburban principal arterial shows higher speeds than expected.

Bluetooth detection on US 14 east of Janesville, a suburban principal arterial shown in Section 4.2.4, seems to be recording especially high speeds, especially during the PM peak period where one would expect to see slower speeds due to the evening rush of traffic leaving Janesville. Both NPMRDS and TomTom report similar travel times throughout all time intervals on the route.

The short rural arterial shows large variation in travel times.

Speeds for WIS 73 (Section 4.2.5), which was chosen as an intentionally short rural arterial, seem to vary across the board. TomTom and NPMRDS seem to offer more reasonable travel times, but the single microwave detector on the route shows average speeds well above the posted speed. These speeds are only 5 mi/hr above the posted speed, but they seem high for an average. However, noting the location of this detector on the north end of the route, the rural end, this could be reason enough for the discrepancy. The other detection methods are collecting vehicles exiting the freeway and beginning on the route (or vice versa), which will severely reduce average speed on such a short route.

The urban principal arterial shows expected travel times.

All detection methods on US 151 / East Washington Avenue, an urban principal arterial in Madison shown in Section 4.2.6, seem reasonable. However, it should be noted that NPMRDS travel times tend to report quicker travel times than either TomTom or Bluetooth. This segment is somewhat unique in that the facility performs worst in both directions during the PM rush period, and this is correctly shown by all detection methods. These results are promising for accurate travel time performance for all detection types covering long enough distances on urban arterials.

The rural freeway shows expected travel times.

Speeds on I-39/90, a rural freeway shown in Section 4.2.7, all seem reasonable as well. However, microwave detection seems to be faster in general followed by TomTom. This makes sense for microwave as these are time-mean speeds and for TomTom as the data are more heavily weighted towards passenger vehicles. This trend is also shown in Figure 4.18, where TomTom is faster than NPMRDS.

The urban freeway shows some unexpected travel times due to 2015 route inconsistencies.

For US 12, the beltline in Madison shown in Section 4.2.8, all detection methods are present. Travel times from microwave detection seem to be faster, especially for 2015 data. Comparing this with data availability, there was an issue with availability for microwave detection in 2015 being sporadic for certain detectors, so these results are not unexpected.

4.2.1. Travel Times and Speeds for US 12/18 (Rural Principal Arterial)

Table 4.2. US 12/18 Average Travel Speeds, April 15 - May 4, 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	56.1 | 58.1	56.6 | 58.4	56.7 | 56.1	N/A
AM Peak (07:30-08:30 M-F)	54.9 | 57.3	56.0 | 58.4	56.8 | 55.1	N/A
PM Rush (15:00-18:00 M-F)	57.7 | 56.8	57.9 | 58.6	58.0 | 56.6	N/A
PM Peak (16:30-17:30 M-F)	58.0 | 58.1	57.0 | 58.7	57.0 | 58.2	N/A
Weekday Daytime (09:00-15:00 M-F)	57.6 | 57.4	56.2 | 57.0	57.3 | 55.7	N/A
Weekend Daytime (07:00-19:00 S-U)	58.0 | 57.8	57.4 | 57.6	58.0 | 57.6	N/A
Nighttime (20:00-04:00 M-U)	57.2 | 57.7	57.7 | 58.0	60.3 | 58.3	N/A

Units are in miles per hour, EB | WB

Table 4.3. US 12/18 Average Travel Times, April 15 - May 4, 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	11.3 | 10.9	11.4 | 10.9	11.3 | 11.4	N/A
AM Peak (07:30-08:30 M-F)	11.6 | 11.1	11.5 | 10.9	11.2 | 11.6	N/A
PM Rush (15:00-18:00 M-F)	11.0 | 11.2	11.0 | 10.9	11.0 | 11.3	N/A
PM Peak (16:30-17:30 M-F)	11.0 | 10.9	11.2 | 10.8	11.2 | 10.9	N/A
Weekday Daytime (09:00-15:00 M-F)	11.1 | 11.1	11.5 | 11.2	11.1 | 11.5	N/A
Weekend Daytime (07:00-19:00 S-U)	11.0 | 11.0	11.1 | 11.1	11.0 | 11.1	N/A
Nighttime (20:00-04:00 M-U)	11.1 | 11.0	11.1 | 11.0	10.6 | 10.9	N/A

Units are in minutes, EB | WB

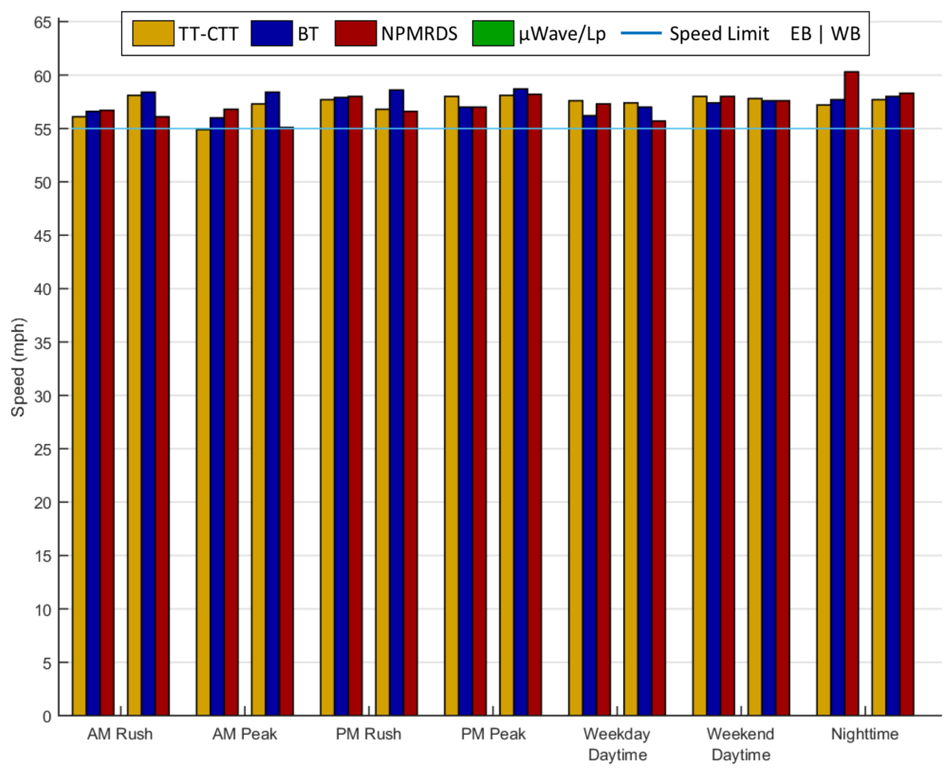


Figure 4.1. US 12/18 Average Travel Speeds, April 15 - May 4, 2015

4.2.2. Travel Times and Speeds for 14M (Suburban Freeway)

Table 4.4. US 14 (Madison) Average Travel Speeds, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	61.0 | 62.4	61.0 | 62.6	64.2 | 64.8	N/A
AM Peak (07:30-08:30 M-F)	60.9 | 61.9	60.9 | 61.5	64.2 | 63.5	N/A
PM Rush (15:00-18:00 M-F)	64.6 | 65.4	63.2 | 64.4	65.6 | 65.3	N/A
PM Peak (16:30-17:30 M-F)	64.8 | 65.2	63.5 | 64.8	65.8 | 65.7	N/A
Weekday Daytime (09:00-15:00 M-F)	62.2 | 63.9	61.1 | 63.5	63.4 | 64.1	N/A
Weekend Daytime (07:00-19:00 S-U)	63.6 | 65.0	62.3 | 64.8	63.2 | 66.3	N/A
Nighttime (20:00-04:00 M-U)	64.1 | 61.4	62.0 | 63.1	62.3 | 63.4	N/A

Units are in miles per hour, EB | WB

Table 4.5. US 14 (Madison) Average Travel Times, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	6.2 | 6.1	6.2 | 6.1	5.9 | 5.9	N/A
AM Peak (07:30-08:30 M-F)	6.2 | 6.1	6.2 | 6.2	5.9 | 6.0	N/A
PM Rush (15:00-18:00 M-F)	5.8 | 5.8	6.0 | 5.9	5.8 | 5.8	N/A
PM Peak (16:30-17:30 M-F)	5.8 | 5.8	6.0 | 5.8	5.8 | 5.8	N/A
Weekday Daytime (09:00-15:00 M-F)	6.1 | 5.9	6.2 | 6.0	6.0 | 5.9	N/A
Weekend Daytime (07:00-19:00 S-U)	5.9 | 5.8	6.1 | 5.8	6.0 | 5.7	N/A
Nighttime (20:00-04:00 M-U)	5.9 | 6.1	6.1 | 6.0	6.1 | 6.0	N/A

Units are in minutes, EB | WB

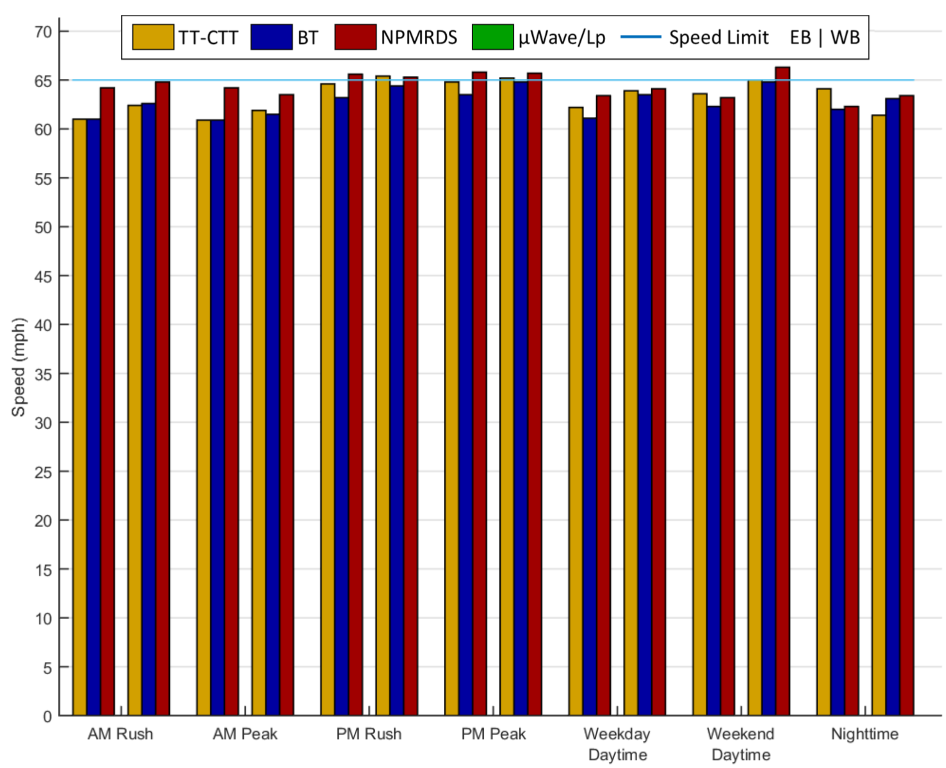


Figure 4.2. US 14 (Madison) Average Travel Speeds, May 2015

Table 4.6. US 14 (Madison) Average Travel Speeds, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	62.2 | 57.6	60.9 | 62.9	64.5 | 66.3	N/A
AM Peak (07:30-08:30 M-F)	64.4 | 58.6	60.9 | 61.0	64.6 | 66.1	N/A
PM Rush (15:00-18:00 M-F)	63.1 | 63.4	64.9 | 65.0	67.5 | 66.4	N/A
PM Peak (16:30-17:30 M-F)	64.6 | 62.9	65.2 | 65.0	67.4 | 66.9	N/A
Weekday Daytime (09:00-15:00 M-F)	61.4 | 64.9	62.4 | 64.6	65.1 | 65.6	N/A
Weekend Daytime (07:00-19:00 S-U)	65.7 | 66.8	64.4 | 66.5	66.4 | 68.0	N/A
Nighttime (20:00-04:00 M-U)	62.9 | 62.7	63.7 | 63.4	63.7 | 65.8	N/A

Units are in miles per hour, EB | WB

Table 4.7. US 14 (Madison) Average Travel Times, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	6.1 | 6.6	6.2 | 6.1	5.9 | 5.8	N/A
AM Peak (07:30-08:30 M-F)	5.9 | 6.5	6.2 | 6.3	5.9 | 5.8	N/A
PM Rush (15:00-18:00 M-F)	6.0 | 6.0	5.8 | 5.8	5.6 | 5.7	N/A
PM Peak (16:30-17:30 M-F)	5.8 | 6.0	5.8 | 5.8	5.6 | 5.7	N/A
Weekday Daytime (09:00-15:00 M-F)	6.2 | 5.8	6.1 | 5.9	5.8 | 5.8	N/A
Weekend Daytime (07:00-19:00 S-U)	5.7 | 5.7	5.9 | 5.7	5.8 | 5.6	N/A
Nighttime (20:00-04:00 M-U)	6.0 | 6.0	6.0 | 6.0	6.0 | 5.8	N/A

Units are in minutes, EB | WB

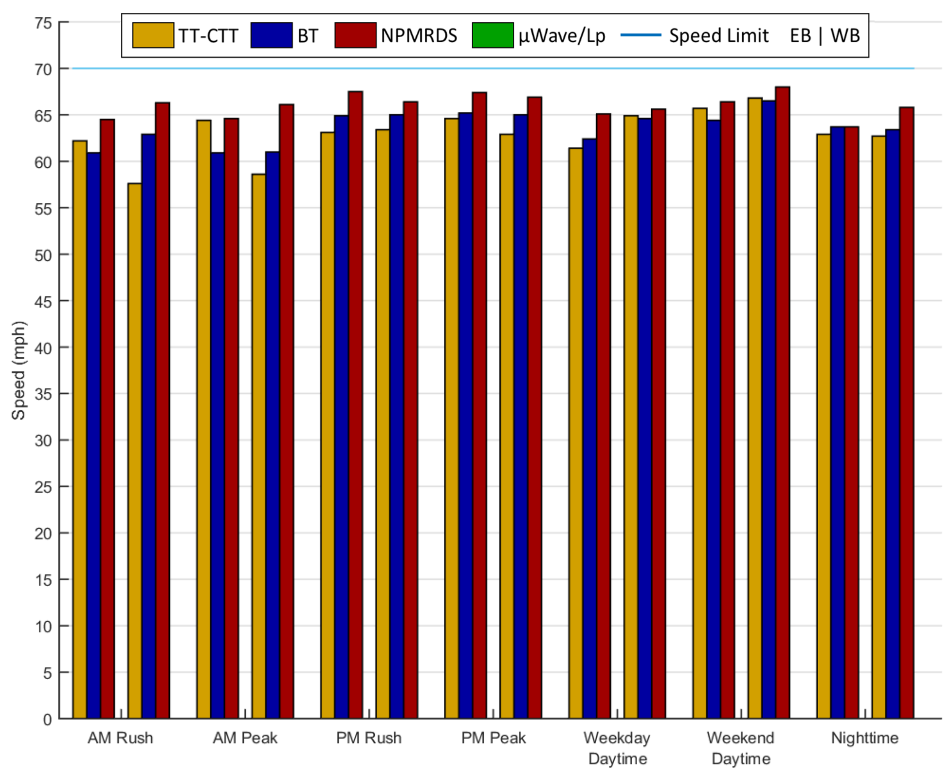


Figure 4.3. US 14 (Madison) Average Travel Speeds, May 2016

4.2.3. Travel Times and Speeds for County M (Rural Minor Arterial)

Table 4.8. County M Average Travel Speeds, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	47.1 | 49.3	N/A	49.1 | 50.1	N/A
AM Peak (07:30-08:30 M-F)	48.3 | 50.5	N/A	50.1 | 50.2	N/A
PM Rush (15:00-18:00 M-F)	48.3 | 48.7	N/A	48.2 | 40.6	N/A
PM Peak (16:30-17:30 M-F)	47.9 | 48.3	N/A	47.4 | 39.7	N/A
Weekday Daytime (09:00-15:00 M-F)	48.1 | 47.2	N/A	46.9 | 43.9	N/A
Weekend Daytime (07:00-19:00 S-U)	49.0 | 51.2	N/A	44.3 | 52.3	N/A
Nighttime (20:00-04:00 M-U)	50.6 | 46.3	N/A	47.5 | 53.6	N/A

Units are in miles per hour, EB | WB

Table 4.9. County M Average Travel Times, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	9.9 | 9.5	N/A	10.4 | 9.5	N/A
AM Peak (07:30-08:30 M-F)	9.7 | 9.3	N/A	10.1 | 9.5	N/A
PM Rush (15:00-18:00 M-F)	9.7 | 9.6	N/A	10.4 | 12.2	N/A
PM Peak (16:30-17:30 M-F)	9.8 | 9.7	N/A	10.4 | 13.0	N/A
Weekday Daytime (09:00-15:00 M-F)	9.7 | 9.9	N/A	11.1 | 12.2	N/A
Weekend Daytime (07:00-19:00 S-U)	9.5 | 9.1	N/A	12.3 | 9.3	N/A
Nighttime (20:00-04:00 M-U)	9.2 | 10.1	N/A	10.5 | 8.7	N/A

Units are in minutes, EB | WB

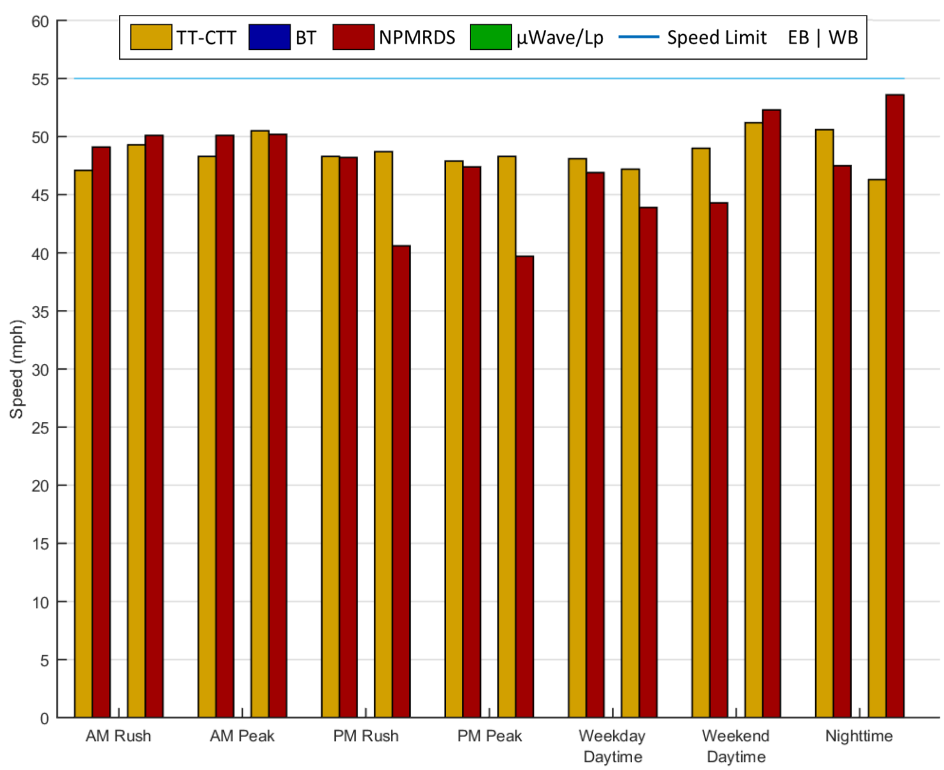


Figure 4.4. County M Average Travel Speeds, May 2015

Table 4.10. County M Average Travel Speeds, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	46.1 | 48.4	N/A	46.2 | 49.4	N/A
AM Peak (07:30-08:30 M-F)	47.5 | 48.3	N/A	46.5 | 48.9	N/A
PM Rush (15:00-18:00 M-F)	46.0 | 48.0	N/A	47.4 | 50.5	N/A
PM Peak (16:30-17:30 M-F)	45.2 | 48.6	N/A	46.1 | 51.1	N/A
Weekday Daytime (09:00-15:00 M-F)	46.8 | 46.9	N/A	46.1 | 48.3	N/A
Weekend Daytime (07:00-19:00 S-U)	49.0 | 50.0	N/A	48.0 | 49.7	N/A
Nighttime (20:00-04:00 M-U)	49.8 | 44.4	N/A	51.8 | 51.6	N/A

Units are in miles per hour, EB | WB

Table 4.11. County M Average Travel Times, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	10.1 | 9.7	N/A	10.6 | 9.7	N/A
AM Peak (07:30-08:30 M-F)	9.8 | 9.7	N/A	10.5 | 9.8	N/A
PM Rush (15:00-18:00 M-F)	10.2 | 9.7	N/A	10.3 | 9.5	N/A
PM Peak (16:30-17:30 M-F)	10.4 | 9.6	N/A	10.6 | 9.4	N/A
Weekday Daytime (09:00-15:00 M-F)	10.0 | 10.0	N/A	10.7 | 10.0	N/A
Weekend Daytime (07:00-19:00 S-U)	9.5 | 9.4	N/A	10.5 | 9.8	N/A
Nighttime (20:00-04:00 M-U)	9.4 | 10.5	N/A	9.3 | 9.3	N/A

Units are in minutes, EB | WB

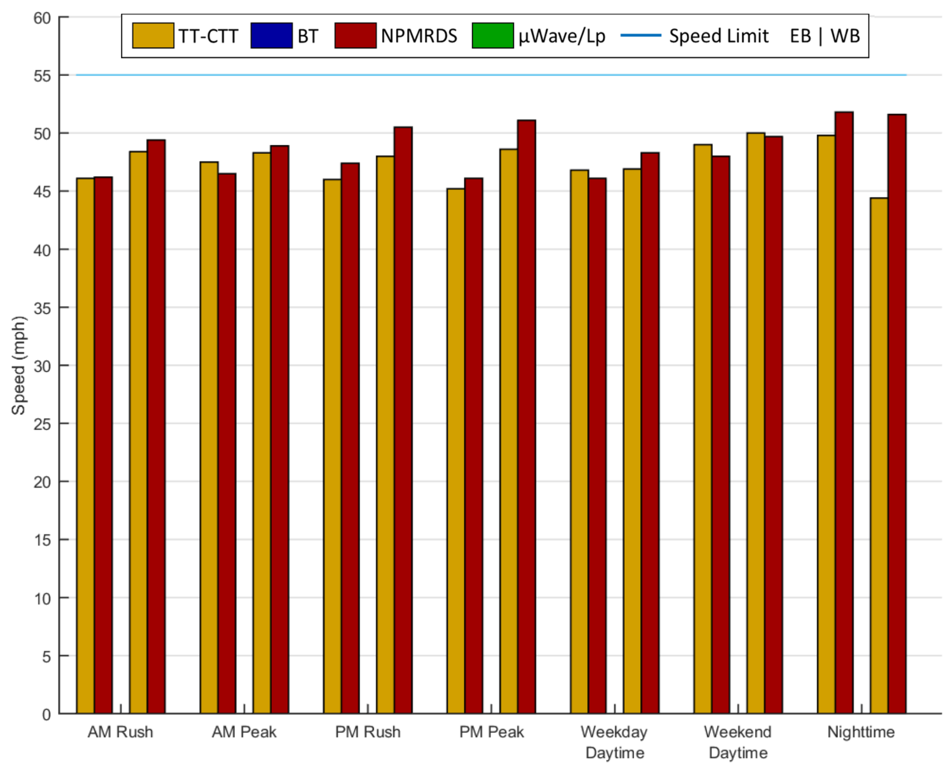


Figure 4.5. County M Average Travel Speeds, May 2016

4.2.4. Travel Times and Speeds for US 14J (Suburban Principal Arterial)

Table 4.12. US 14 (Janesville) Average Travel Speeds, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	47.0 | 44.7	49.6 | 51.7	47.2 | 47.6	N/A
AM Peak (07:30-08:30 M-F)	45.5 | 41.8	50.0 | 52.0	46.9 | 47.8	N/A
PM Rush (15:00-18:00 M-F)	46.2 | 46.0	53.2 | 50.6	48.2 | 47.6	N/A
PM Peak (16:30-17:30 M-F)	47.0 | 45.8	57.8 | 51.3	48.2 | 46.6	N/A
Weekday Daytime (09:00-15:00 M-F)	47.5 | 45.4	50.1 | 50.4	48.1 | 47.8	N/A
Weekend Daytime (07:00-19:00 S-U)	47.3 | 46.3	51.5 | 51.1	49.8 | 49.3	N/A
Nighttime (20:00-04:00 M-U)	48.8 | 49.3	54.6 | 52.1	50.8 | 49.5	N/A

Units are in miles per hour, EB | WB

Table 4.13. US 14 (Janesville) Average Travel Times, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	12.0 | 12.6	11.8 | 11.0	12.1 | 12.0	N/A
AM Peak (07:30-08:30 M-F)	12.4 | 13.5	11.8 | 10.9	12.2 | 11.9	N/A
PM Rush (15:00-18:00 M-F)	12.2 | 12.2	11.3 | 11.3	11.8 | 12.0	N/A
PM Peak (16:30-17:30 M-F)	12.0 | 12.3	10.7 | 11.2	11.8 | 12.4	N/A
Weekday Daytime (09:00-15:00 M-F)	11.9 | 12.4	11.8 | 11.4	11.9 | 11.9	N/A
Weekend Daytime (07:00-19:00 S-U)	11.9 | 12.2	11.2 | 11.3	11.5 | 11.7	N/A
Nighttime (20:00-04:00 M-U)	11.6 | 11.4	11.8 | 11.3	11.2 | 11.6	N/A

Units are in minutes, EB | WB

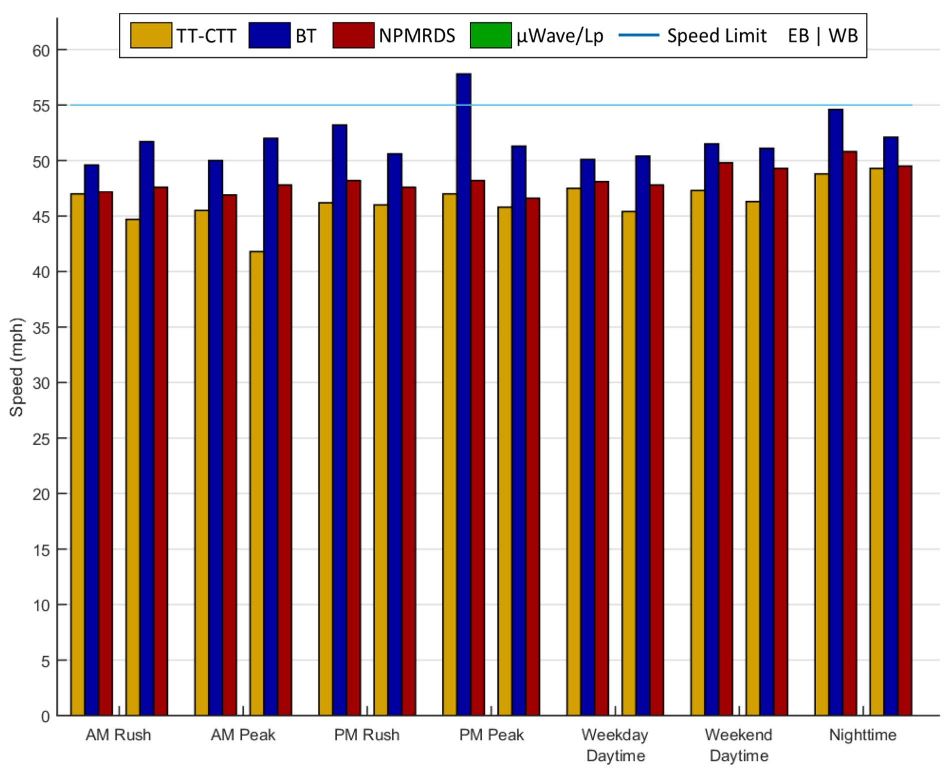


Figure 4.6. US 14 (Janesville) Average Travel Speeds, May 2015

4.2.5. Travel Times and Speeds for WIS 73 (Rural Minor Arterial)

Table 4.14. WIS 73 Average Travel Speeds, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	39.9 | 45.2	N/A	38.7 | 34.5	60.1 | 60.9
AM Peak (07:30-08:30 M-F)	40.8 | 51.1	N/A	35.4 | 35.3	59.9 | 61.1
PM Rush (15:00-18:00 M-F)	45.8 | 40.0	N/A	42.0 | 36.8	62.6 | 60.4
PM Peak (16:30-17:30 M-F)	45.2 | 43.6	N/A	40.4 | 34.5	63.9 | 61.7
Weekday Daytime (09:00-15:00 M-F)	41.2 | 41.0	N/A	40.3 | 34.6	58.0 | 55.8
Weekend Daytime (07:00-19:00 S-U)	42.1 | 44.2	N/A	43.5 | 37.8	64.4 | 63.7
Nighttime (20:00-04:00 M-U)	40.9 | 39.1	N/A	43.7 | 29.0	58.6 | 60.3

Units are in miles per hour, NB | SB

Table 4.15. WIS 73 Average Travel Times, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	1.2 | 1.1	N/A	1.4 | 1.6	0.8 | 0.8
AM Peak (07:30-08:30 M-F)	1.2 | 0.9	N/A	1.6 | 1.6	0.8 | 0.8
PM Rush (15:00-18:00 M-F)	1.0 | 1.2	N/A	1.3 | 1.5	0.8 | 0.8
PM Peak (16:30-17:30 M-F)	1.0 | 1.1	N/A	1.3 | 1.5	0.8 | 0.8
Weekday Daytime (09:00-15:00 M-F)	1.2 | 1.2	N/A	1.3 | 1.6	0.8 | 0.9
Weekend Daytime (07:00-19:00 S-U)	1.1 | 1.1	N/A	1.2 | 1.4	0.7 | 0.8
Nighttime (20:00-04:00 M-U)	1.2 | 1.2	N/A	1.2 | 1.9	0.8 | 0.8

Units are in minutes, NB | SB

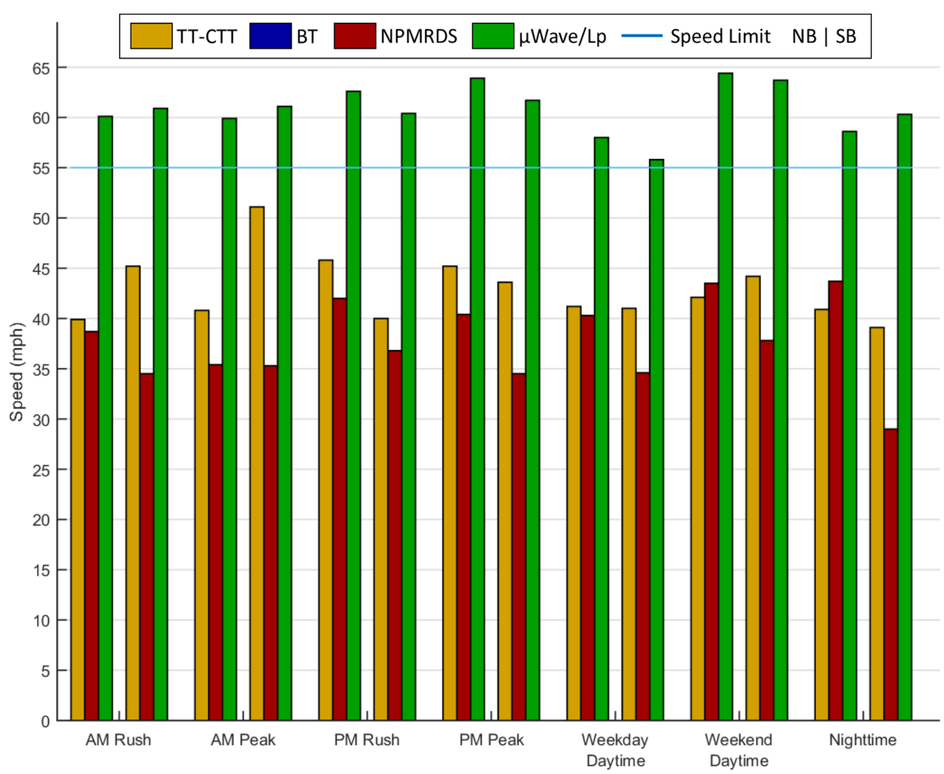


Figure 4.7. WIS 73 Average Travel Speeds, May 2015

Table 4.16. WIS 73 Average Travel Speeds, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	43.6 | 47.4	N/A	43.8 | 40.4	60.4 | 61.8
AM Peak (07:30-08:30 M-F)	40.5 | 44.8	N/A	42.9 | 38.3	60.5 | 62.4
PM Rush (15:00-18:00 M-F)	48.0 | 46.9	N/A	47.7 | 35.6	64.1 | 62.8
PM Peak (16:30-17:30 M-F)	45.0 | 53.5	N/A	46.7 | 36.3	64.8 | 63.4
Weekday Daytime (09:00-15:00 M-F)	47.1 | 40.0	N/A	45.7 | 37.2	58.4 | 58.2
Weekend Daytime (07:00-19:00 S-U)	45.5 | 45.7	N/A	49.7 | 35.8	63.6 | 64.0
Nighttime (20:00-04:00 M-U)	41.1 | 44.3	N/A	44.6 | 26.3	58.8 | 62.6

Units are in miles per hour, NB | SB

Table 4.17. WIS 73 Average Travel Times, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	1.1 | 1.0	N/A	1.2 | 1.4	0.8 | 0.8
AM Peak (07:30-08:30 M-F)	1.2 | 1.1	N/A	1.3 | 1.4	0.8 | 0.8
PM Rush (15:00-18:00 M-F)	1.0 | 1.0	N/A	1.1 | 1.6	0.7 | 0.8
PM Peak (16:30-17:30 M-F)	1.1 | 0.9	N/A	1.1 | 1.6	0.7 | 0.8
Weekday Daytime (09:00-15:00 M-F)	1.0 | 1.2	N/A	1.1 | 1.5	0.8 | 0.8
Weekend Daytime (07:00-19:00 S-U)	1.0 | 1.0	N/A	1.0 | 1.5	0.8 | 0.8
Nighttime (20:00-04:00 M-U)	1.2 | 1.1	N/A	1.2 | 2.1	0.8 | 0.8

Units are in minutes, NB | SB

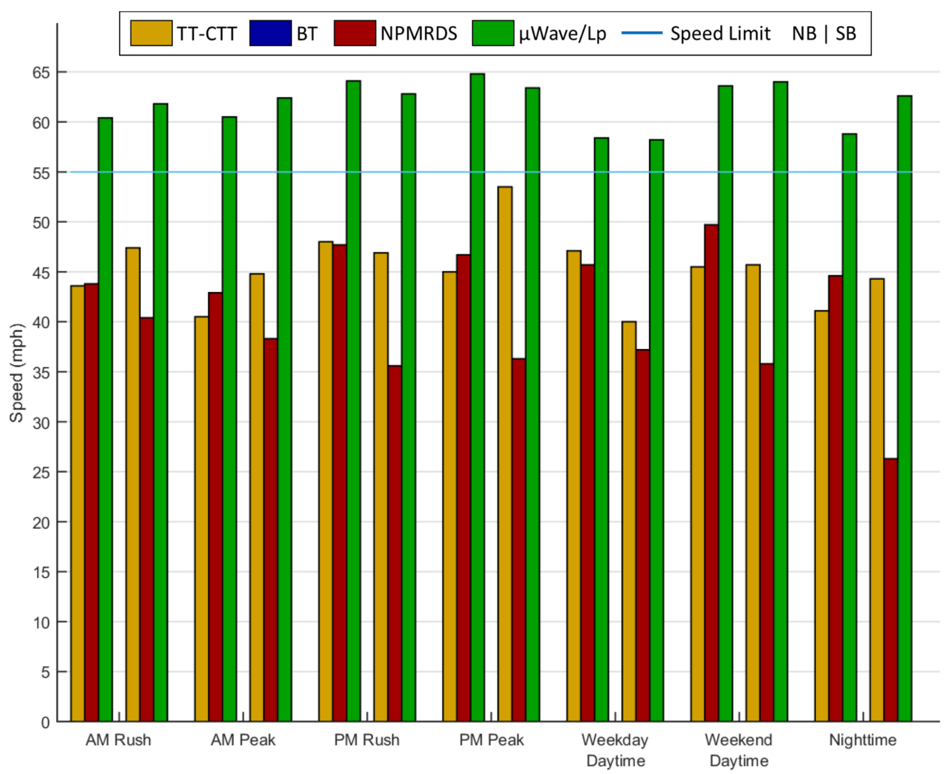


Figure 4.8. WIS 73 Average Travel Speeds, May 2016

4.2.6. Travel Times and Speeds for US 151 (Urban Principal Arterial)

Table 4.18. US 151 Average Travel Speeds, July 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	26.4 | 24.1	24.2 | 23.6	28.4 | 26.0	N/A
AM Peak (07:30-08:30 M-F)	26.4 | 22.7	24.4 | 22.5	28.2 | 25.4	N/A
PM Rush (15:00-18:00 M-F)	22.1 | 21.7	21.6 | 20.8	25.8 | 25.0	N/A
PM Peak (16:30-17:30 M-F)	19.9 | 20.3	20.0 | 19.6	24.2 | 24.0	N/A
Weekday Daytime (09:00-15:00 M-F)	25.0 | 24.7	23.4 | 22.6	27.4 | 25.9	N/A
Weekend Daytime (07:00-19:00 S-U)	27.1 | 25.8	26.4 | 24.5	30.1 | 27.8	N/A
Nighttime (20:00-04:00 M-U)	28.2 | 27.8	27.2 | 26.7	31.7 | 29.8	N/A

Units are in miles per hour, NB | SB

Table 4.19. US 151 Average Travel Times, July 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	10.5 | 11.4	11.6 | 11.8	10.0 | 10.9	N/A
AM Peak (07:30-08:30 M-F)	10.5 | 12.1	11.5 | 12.4	10.1 | 11.2	N/A
PM Rush (15:00-18:00 M-F)	12.5 | 12.7	13.1 | 13.4	11.0 | 11.4	N/A
PM Peak (16:30-17:30 M-F)	13.9 | 13.6	14.3 | 14.2	11.7 | 11.8	N/A
Weekday Daytime (09:00-15:00 M-F)	11.0 | 11.2	12.0 | 12.4	10.4 | 10.9	N/A
Weekend Daytime (07:00-19:00 S-U)	10.2 | 10.7	10.7 | 11.5	9.4 | 10.2	N/A
Nighttime (20:00-04:00 M-U)	9.8 | 9.9	10.6 | 10.9	8.9 | 9.5	N/A

Units are in minutes, NB | SB

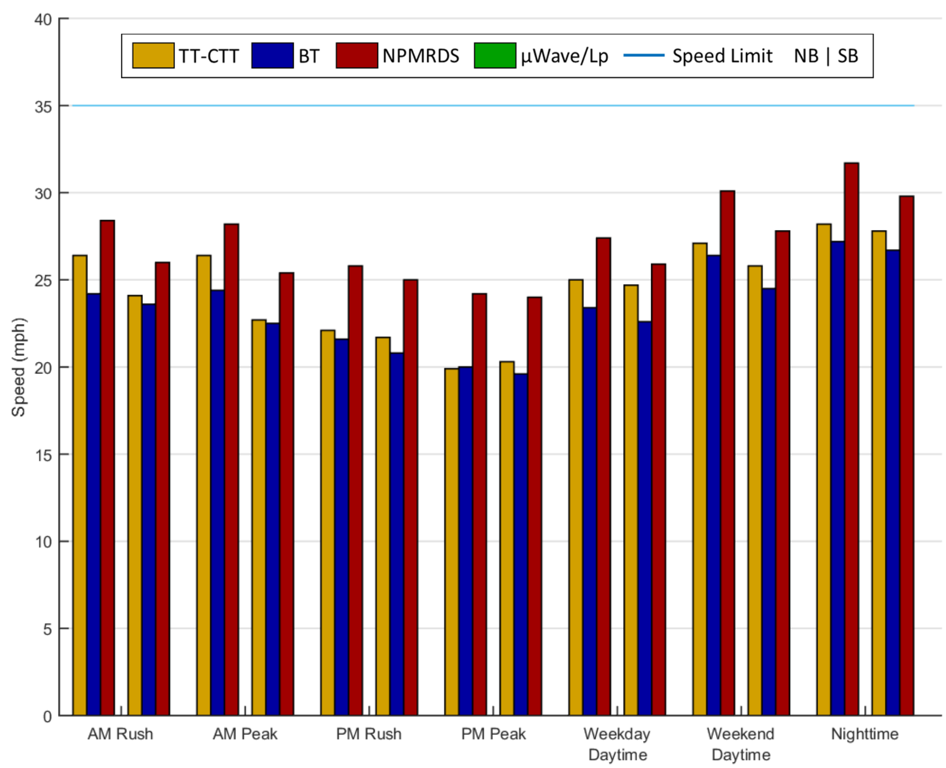


Figure 4.9. US 151 Average Travel Speeds, July 2016

4.2.7. Travel Times and Speeds for I-39/90 (Rural Freeway)

Table 4.20. I-39/90 Average Travel Speeds, July 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	68.3 | 68.7	66.8 | 67.1	65.4 | 65.5	68.5 | 66.6
AM Peak (07:30-08:30 M-F)	68.6 | 68.6	66.8 | 67.2	65.5 | 65.5	68.7 | 66.6
PM Rush (15:00-18:00 M-F)	61.1 | 65.1	63.4 | 64.5	62.7 | 63.5	66.7 | 65.0
PM Peak (16:30-17:30 M-F)	63.8 | 64.9	64.4 | 64.0	63.0 | 62.7	66.8 | 64.8
Weekday Daytime (09:00-15:00 M-F)	64.5 | 68.1	64.5 | 66.2	64.0 | 65.6	65.9 | 65.1
Weekend Daytime (07:00-19:00 S-U)	69.4 | 60.0	67.7 | 62.8	66.2 | 62.1	69.4 | 65.0
Nighttime (20:00-04:00 M-U)	65.6 | 65.1	64.0 | 64.5	63.2 | 63.5	64.2 | 62.6

Units are in miles per hour, NB | SB

Table 4.21. I-39/90 Average Travel Times, July 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	43.5 | 43.2	44.5 | 44.3	45.4 | 45.4	43.4 | 44.6
AM Peak (07:30-08:30 M-F)	43.3 | 43.3	44.5 | 44.2	45.4 | 45.3	43.2 | 44.6
PM Rush (15:00-18:00 M-F)	48.6 | 45.6	47.4 | 46.3	47.9 | 47.0	44.6 | 45.7
PM Peak (16:30-17:30 M-F)	46.6 | 45.7	46.6 | 46.6	47.7 | 47.6	44.5 | 45.9
Weekday Daytime (09:00-15:00 M-F)	46.0 | 43.6	46.3 | 44.9	46.7 | 45.4	45.0 | 45.6
Weekend Daytime (07:00-19:00 S-U)	42.8 | 49.5	44.0 | 48.7	44.9 | 48.9	42.8 | 45.7
Nighttime (20:00-04:00 M-U)	45.3 | 45.6	46.6 | 46.2	47.1 | 46.9	46.2 | 47.4

Units are in minutes, NB | SB

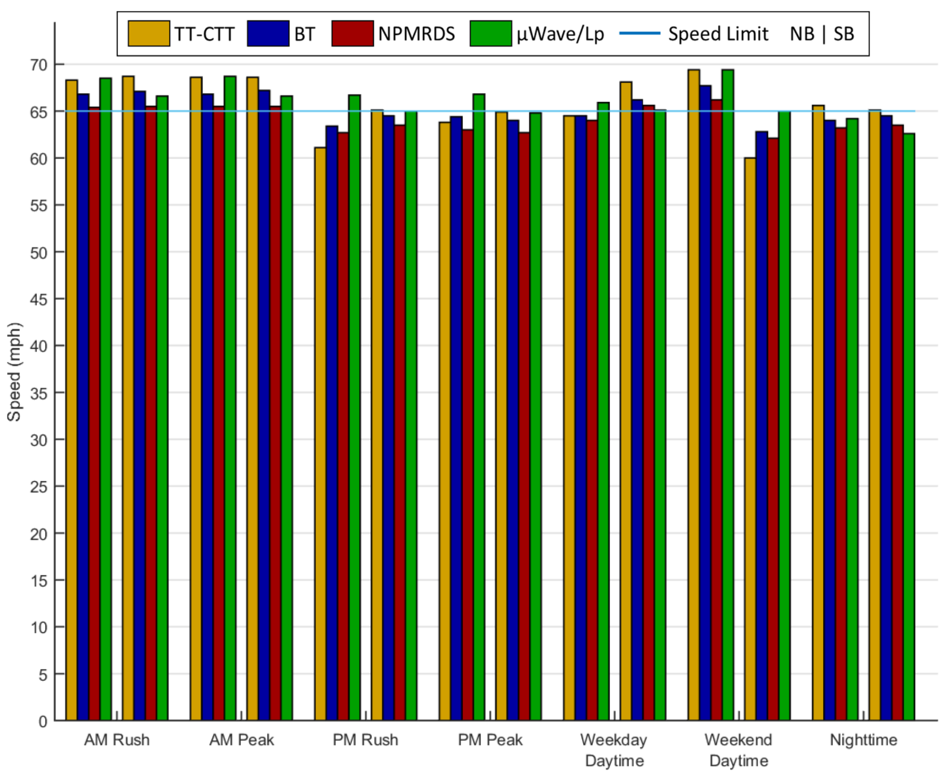


Figure 4.10. I-39/90 Average Travel Speeds, July 2015

Table 4.22. I-39/90 Average Travel Speeds, July 2016

Time Period	TT – CTT	BT	NPMRDS	μWave/Loop
AM Rush (07:00-09:00 M-F)	70.8 | 71.4	66.8 | 67.1	65.5 | 65.5	69.7 | 69.6
AM Peak (07:30-08:30 M-F)	70.7 | 71.4	66.8 | 67.2	65.5 | 65.5	69.7 | 69.7
PM Rush (15:00-18:00 M-F)	61.2 | 65.3	64.4 | 62.4	63.3 | 61.9	68.0 | 67.9
PM Peak (16:30-17:30 M-F)	61.8 | 64.2	64.7 | 61.6	63.0 | 61.3	68.1 | 67.1
Weekday Daytime (09:00-15:00 M-F)	64.8 | 69.1	64.9 | 65.6	64.2 | 64.7	67.4 | 68.4
Weekend Daytime (07:00-19:00 S-U)	64.3 | 63.8	66.1 | 63.8	65.0 | 62.5	70.4 | 70.0
Nighttime (20:00-04:00 M-U)	66.8 | 66.1	63.4 | 61.8	62.4 | 60.4	67.3 | 68.1

Units are in miles per hour, NB | SB

Table 4.23. I-39/90 Average Travel Times, July 2016

Time Period	TT – CTT	BT	NPMRDS	μWave/Loop
AM Rush (07:00-09:00 M-F)	42.0 | 41.6	44.5 | 44.3	45.3 | 45.4	42.6 | 42.7
AM Peak (07:30-08:30 M-F)	42.0 | 41.6	44.5 | 44.2	45.4 | 45.4	42.6 | 42.6
PM Rush (15:00-18:00 M-F)	48.5 | 45.5	46.8 | 47.9	47.5 | 48.3	43.7 | 43.7
PM Peak (16:30-17:30 M-F)	48.0 | 46.2	46.5 | 48.5	47.8 | 48.8	43.6 | 44.2
Weekday Daytime (09:00-15:00 M-F)	45.8 | 43.0	46.3 | 45.3	46.6 | 46.0	44.0 | 43.4
Weekend Daytime (07:00-19:00 S-U)	46.2 | 46.5	45.4 | 47.4	46.1 | 48.3	42.2 | 42.4
Nighttime (20:00-04:00 M-U)	44.5 | 44.9	47.0 | 48.4	47.8 | 49.5	44.2 | 43.6

Units are in minutes, NB | SB

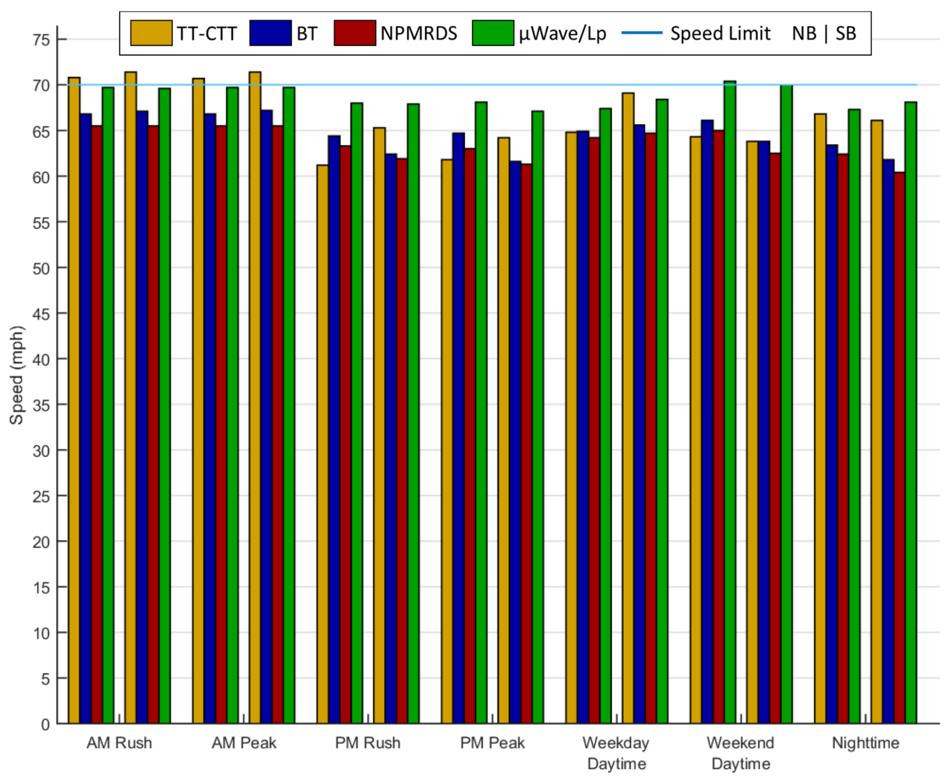


Figure 4.11. I-39/90 Average Travel Speeds, July 2016

4.2.8. Travel Times and Speeds for US 12 (Urban Freeway)

Table 4.24. US 12 Average Travel Speeds, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	57.4 | 44.8	59.1 | 46.9	56.6 | 48.4	63.7 | 48.9
AM Peak (07:30-08:30 M-F)	57.2 | 39.3	58.6 | 40.7	56.2 | 44.1	62.6 | 41.1
PM Rush (15:00-18:00 M-F)	45.2 | 52.6	47.5 | 53.2	49.3 | 52.7	53.2 | 54.3
PM Peak (16:30-17:30 M-F)	38.6 | 47.6	40.0 | 48.0	43.2 | 48.6	43.0 | 46.3
Weekday Daytime (09:00-15:00 M-F)	57.1 | 57.1	58.7 | 58.6	56.5 | 56.3	64.5 | 62.2
Weekend Daytime (07:00-19:00 S-U)	59.0 | 59.6	60.1 | 60.6	58.4 | 58.4	66.4 | 64.0
Nighttime (20:00-04:00 M-U)	56.7 | 57.2	56.9 | 56.6	56.3 | 57.4	64.4 | 62.3

Units are in miles per hour, EB | WB

Table 4.25. US 12 Average Travel Times, May 2015

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	18.5 | 23.7	18.0 | 23.6	18.8 | 22.4	16.7 | 21.7
AM Peak (07:30-08:30 M-F)	18.6 | 27.0	18.2 | 27.0	19.0 | 24.4	17.0 | 25.8
PM Rush (15:00-18:00 M-F)	23.5 | 20.2	23.4 | 20.2	22.0 | 20.3	20.0 | 19.6
PM Peak (16:30-17:30 M-F)	27.5 | 22.3	27.7 | 22.5	25.0 | 22.0	24.7 | 23.0
Weekday Daytime (09:00-15:00 M-F)	18.6 | 18.6	18.1 | 18.1	18.8 | 18.9	16.5 | 17.1
Weekend Daytime (07:00-19:00 S-U)	18.0 | 17.8	17.7 | 17.5	18.2 | 18.2	16.0 | 16.6
Nighttime (20:00-04:00 M-U)	18.7 | 18.6	18.7 | 18.8	19.0 | 18.6	16.5 | 17.0

Units are in minutes, EB | WB

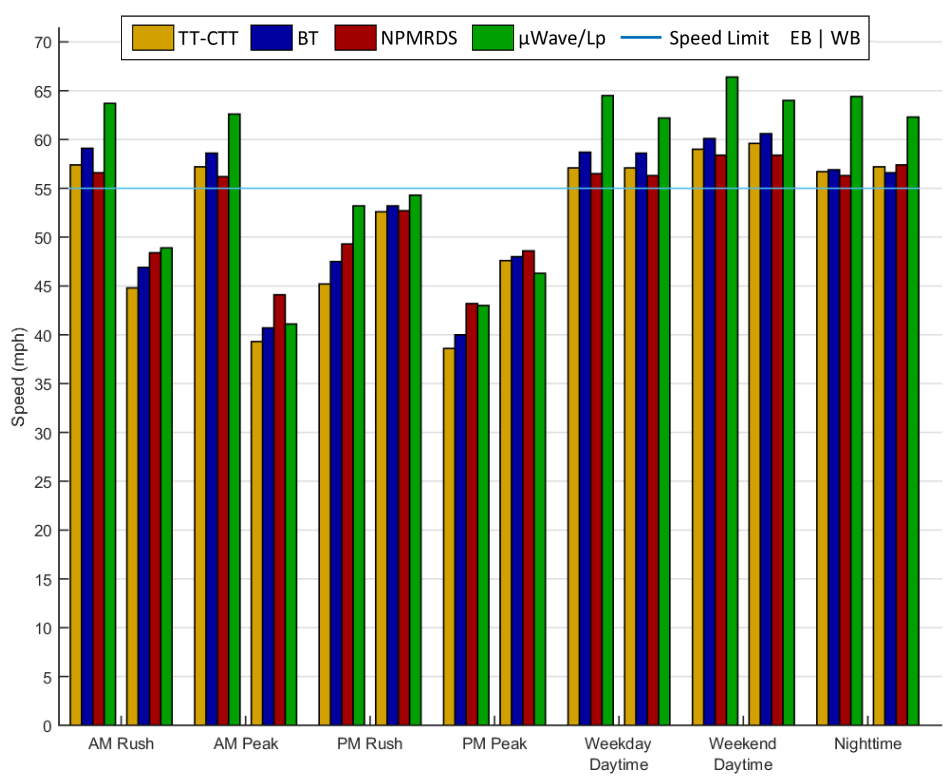


Figure 4.12. US 12 Average Travel Speeds, May 2015

Table 4.26. US 12 Average Travel Speeds, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	57.2 | 41.2	59.3 | 44.0	56.7 | 46.1	54.1 | 39.7
AM Peak (07:30-08:30 M-F)	57.6 | 37.0	58.9 | 40.1	56.3 | 43.8	54.0 | 34.2
PM Rush (15:00-18:00 M-F)	41.9 | 47.2	45.5 | 49.3	48.1 | 50.3	43.3 | 43.3
PM Peak (16:30-17:30 M-F)	34.7 | 43.8	38.0 | 45.1	42.2 | 47.4	36.0 | 36.6
Weekday Daytime (09:00-15:00 M-F)	57.0 | 54.5	59.1 | 56.0	57.3 | 55.3	53.1 | 53.6
Weekend Daytime (07:00-19:00 S-U)	60.0 | 56.0	61.2 | 59.3	58.6 | 56.9	55.4 | 56.2
Nighttime (20:00-04:00 M-U)	57.5 | 57.0	57.6 | 57.4	57.4 | 56.5	53.2 | 55.9

Units are in miles per hour, EB | WB

Table 4.27. US 12 Average Travel Times, May 2016

Time Period	TT – CTT	BT	NPMRDS	µWave/Loop
AM Rush (07:00-09:00 M-F)	18.6 | 25.8	17.9 | 25.0	18.8 | 23.5	19.6 | 26.7
AM Peak (07:30-08:30 M-F)	18.4 | 28.7	18.1 | 27.4	18.9 | 24.6	19.7 | 31.1
PM Rush (15:00-18:00 M-F)	25.3 | 22.5	24.8 | 21.8	22.7 | 21.3	24.5 | 24.5
PM Peak (16:30-17:30 M-F)	30.6 | 24.2	29.5 | 23.9	25.6 | 22.6	29.5 | 29.0
Weekday Daytime (09:00-15:00 M-F)	18.6 | 19.5	18.0 | 19.0	18.6 | 19.2	20.0 | 19.8
Weekend Daytime (07:00-19:00 S-U)	17.7 | 18.9	17.3 | 17.9	18.2 | 18.7	19.2 | 18.9
Nighttime (20:00-04:00 M-U)	18.4 | 18.6	18.5 | 18.5	18.5 | 18.8	20.0 | 19.0

Units are in minutes, EB | WB

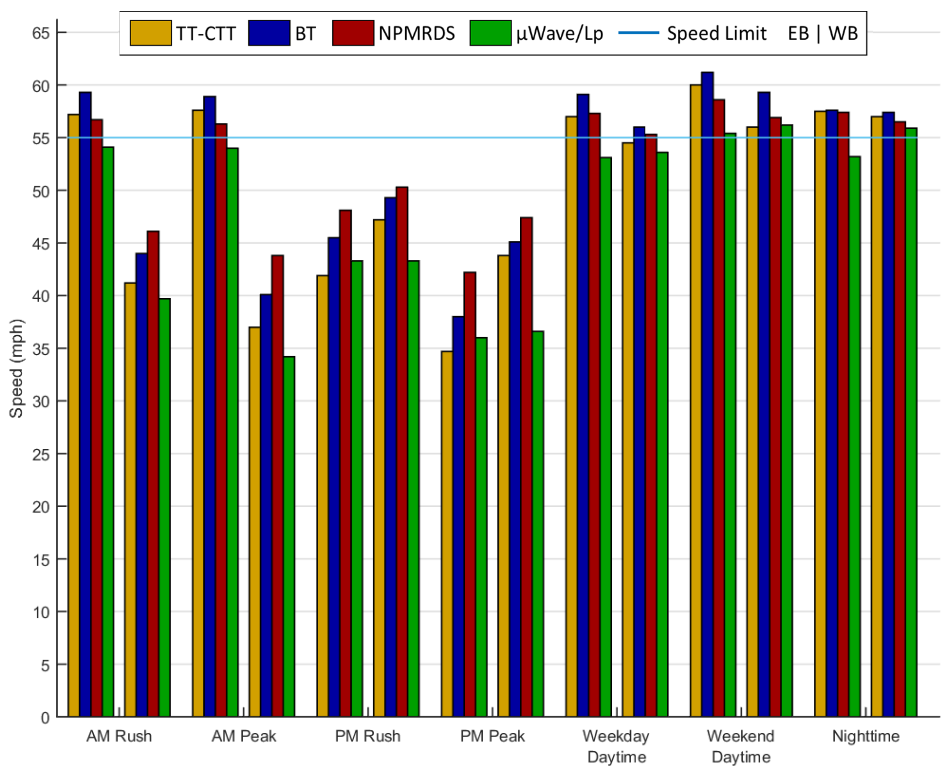


Figure 4.13. US 12 Average Travel Speeds, May 2016

4.3. Additional Travel Times and Speeds Plots

This section includes additional plots where analysis was performed on travel times and speeds for this project. Due to the number of possible plots, not all were included, however samples are shown here to draw some basic conclusions and to allow for a preview of plot types available upon request for any route in this study,

4.3.1. Detailed Speed Comparisons (Short Period, Single Segment)

Figure 4.14 shows a detailed speed comparison of two different detection methods for a single segment over a 24-hour period. A straight horizontal line means a detection was not made for that period so speed is based off the last calculated speed. In this example, average speeds for Bluetooth and NPMRDS tend to follow each other on average, but NPMRDS speeds seem to fluctuate much more drastically. Note this is for one day only and is not necessarily common.

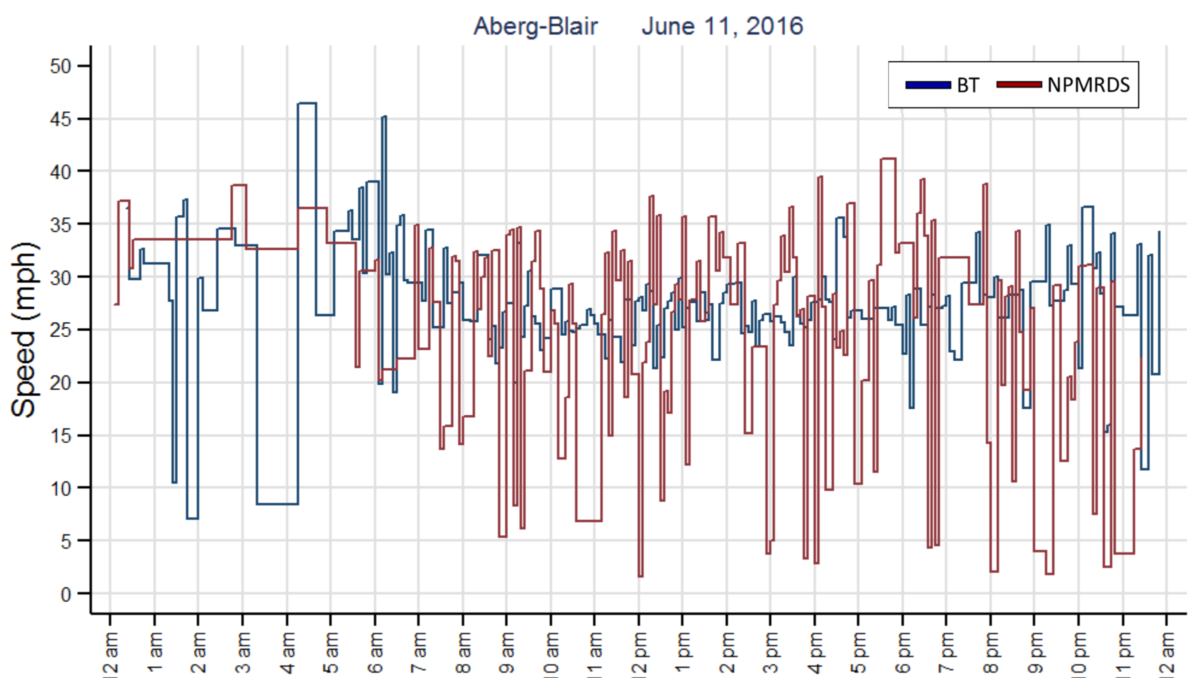


Figure 4.14. Travel Speeds for a Segment of US 151, June 11, 2016

4.3.2. Detailed Speed Comparisons (Long Period, Multiple Segment)

Figures 4.15 and 4.16 show detailed speed comparisons for two different detection methods on average for the entire route over a weeklong period. In these plots, it is more difficult to notice gaps in data, but easier to see how well detection methods trend together. Figure 4.15 shows a comparison of microwave/loop detection and Bluetooth detection for US 12. This is an example of great correspondence between data sets. Figure 4.16 shows the same detection comparison, this time for WIS 73. This is an example of poor correspondence between data sets and shows how sporadic the NPMRDS data are on this route.

Figure 4.15. Detailed Travel Speeds for a US 12, May 2015

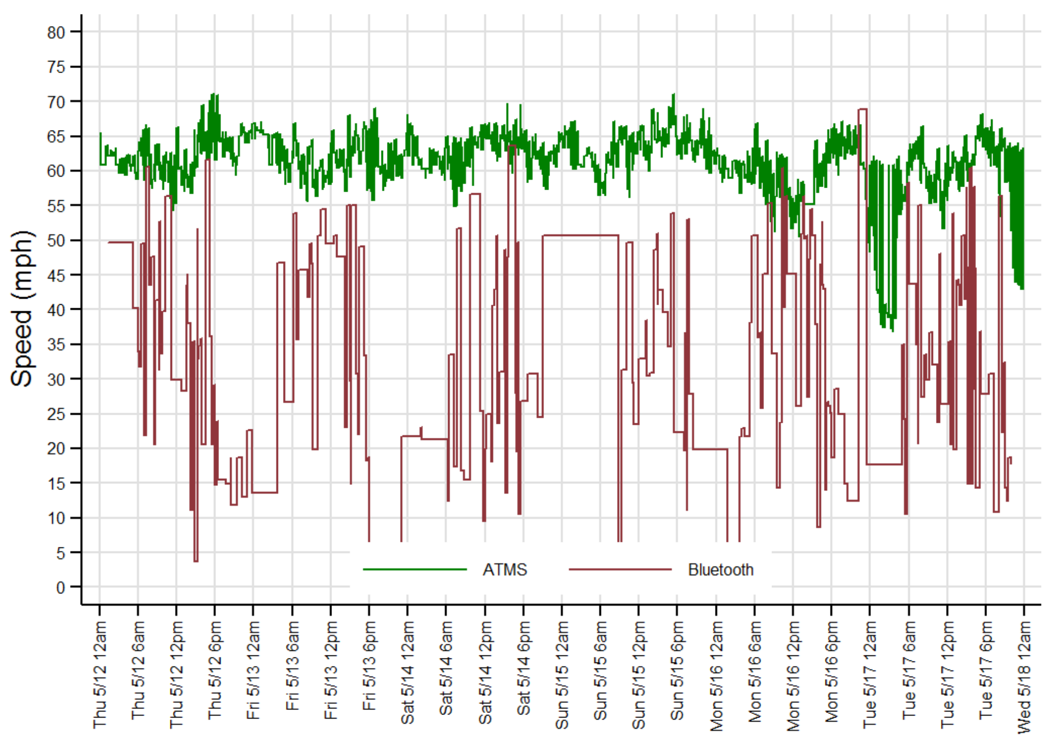


Figure 4.16. Detailed Travel Speeds for WIS 73, May 2015

4.3.3. Cumulative Speed Comparisons

Figures 4.17 and 4.18 show cumulative speed comparisons for two different detection methods over a month period. Both of these plots show the correspondence between NPMRDS and TomTom on I-39/90 for the same month. Figure 4.17 shows all data and Figure 4.18 shows only passenger vehicle data. Speeds for TomTom remain similar, as would be expected based on TomTom's reliance on passenger vehicle data. However, NPMRDS reflects the loss of freight vehicles by showing increased speeds for passenger vehicle only data. Also of note is that TomTom in general reports faster speeds on this route than NPMRDS. Section 4.2.7 shows a full speed comparison for all data detection methods on this route.

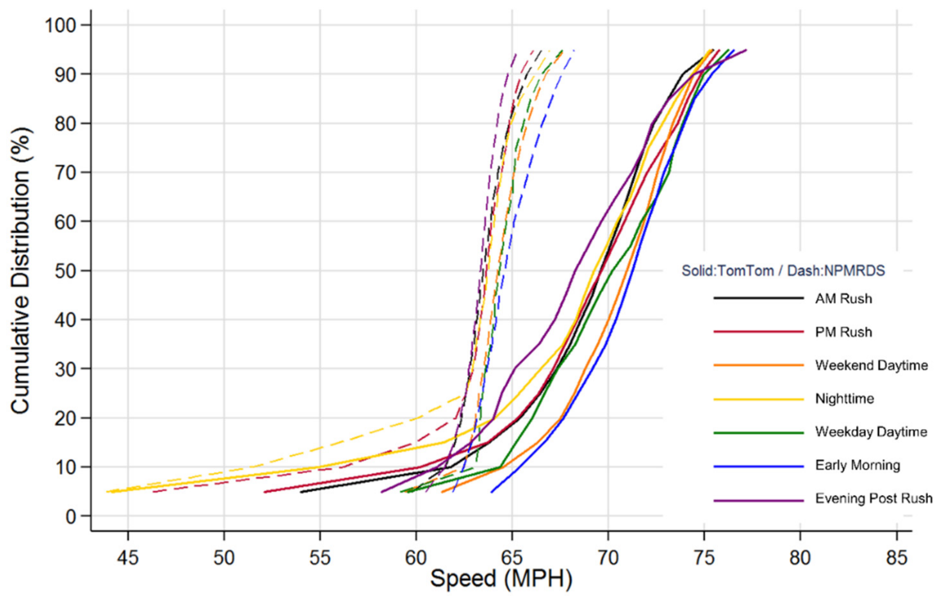


Figure 4.17. Cumulative Distribution of All Vehicle Speeds for I-39 NB, March 2015

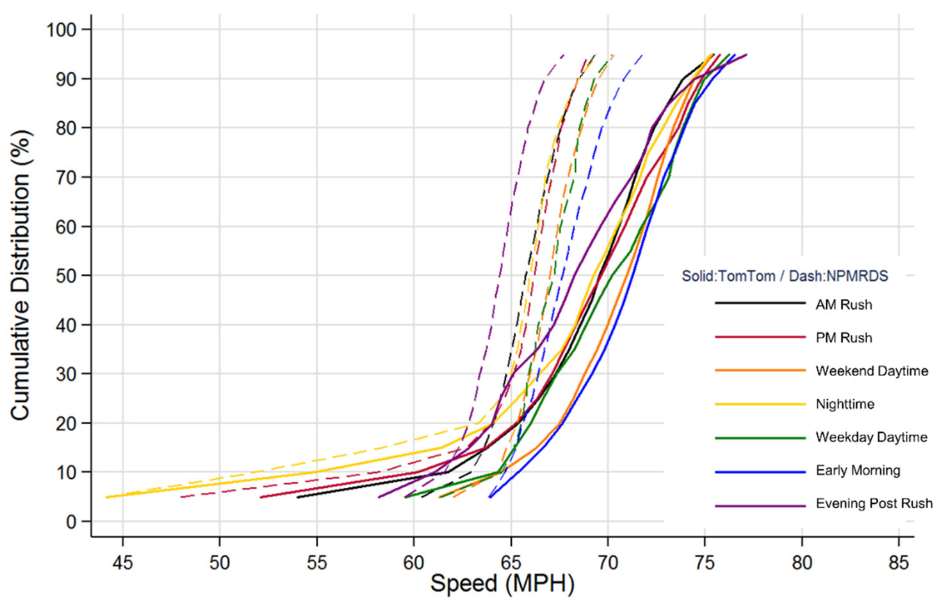


Figure 4.18. Cumulative Distribution of Passenger Vehicle Speeds for I-39 NB, March 2015

4.4. Statistical Analysis

This section reports on the statistical analyses for speeds and travel times for this project. Data from the TomTom CTT do not include detailed time increments (e.g., 5 or 15-minute granularity), so detailed travel time comparisons with those are not possible. Therefore, basic statistics are used for comparison of all technologies and detailed statistics are included for comparisons are between NPMRDS, Bluetooth, and microwave and loop detectors. All corridors except County M provide data from two or three of the later described sources and are used in the detailed statistics section.

General conclusions are presented in Section 4.4.1. Basic statistical analyses and results are included in Section 4.4.2. Detailed statistical analyses are included in Section 4.4.3.

4.4.1. Statistical Analysis Overview and Discussion

The raw data from each source is converted as needed and combined into a single database. All observations are arranged by corridor, direction, date, and time. Travel times from NPMRDS and Bluetooth are converted to speeds using associated distances. Speeds from microwave/loop and NPMRDS are aggregated to 15-minute increments to match Bluetooth data. Detectors from microwave/loop and sub-segments from NPMRDS are averaged per corridor, direction, date, and time. Speeds equal to zero (important for microwave/loop detection) or greater than 100 (Bluetooth) were ignored for this analysis. Note that speeds for this analysis were only used when they had at least one corresponding speed observation from another data source.

Key findings and notes based on statistical analysis results are listed below with reference to specific tables or values when relevant.

Bluetooth detectors have the widest range of speeds, even with outliers removed.

Bluetooth detectors seem to have the widest range of speeds, even with outliers removed, based on values shown in the basic statistics tables. Bluetooth data were extracted using default parameters, which could be adjusted to attain closer matches. Reasons for this are discussed in more detail in Section 3.2.2.

95th percentile speeds correspond well on most routes across detection methods.

95th percentile speeds correspond well on most routes across detection methods. This means that generally most of the detection methods measure similar maximum speeds and is also a good measure of consistency between detection methods.

The detailed statistical analyses show mixed results between detection methods.

Some results of the detailed statistical analyses indicate closer matches than others, as well as general trends.

Point speeds are generally faster than probe-based speeds.

In all cases, microwave/loop speeds are higher than either Bluetooth or NPMRDS. This may in part be attributable to the technical distinction between time mean speeds (such as from spot speeds from point detectors) and space mean speeds (from probe data such as Bluetooth and NPMRDS), the latter always being slower by definition. Bluetooth and NPMRDS vary in which one provides higher speeds.

Higher AADT routes show mixed results with detailed statistics.

Closely matched travel times include I-39/90 between NPMRDS and Bluetooth, and US 12 between microwave/loop data and NPMRDS. Both examples have low MAE, RMSE, and U, with strong correlation. I-39/90 indicates that variances (Us) are substantially different, while US 12 shows that bias exists (which may be attributable to calculation methods or calibration issues).

The short rural arterial shows large variances in travel times between detection types.

WIS 73 on the other hand is a clear outlier in this set. The microwave/loop data give an average speed of 61 mph, compared to 34 mph for NPMRDS. Variances are similar, but errors and bias are all substantial. This is expected based on initial results of tables in Section 4.2.

4.4.2. Basic Statistics

Basic statistics calculated include mean speed, standard deviation, 5th and 95th percentile speeds, and minimum and maximum speeds. Tables 4.28 through 4.35 show these summary statistics for the travel time data, presented by route.

Table 4.28. US 12/18 Basic Travel Speed Statistics

Detection Type	Mean Speed	Standard Deviation	5th Percentile Speed	95th Percentile Speed	Minimum Speed	Maximum Speed
TomTom CTT	57.33	N/A	47.96	63.50	N/A	N/A
Bluetooth	57.81	5.40	52.01	62.24	15.45	88.48
NPMRDS	57.16	3.97	51.01	61.98	17.94	72.95
µWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A

Units are in miles per hour

Table 4.29. US 14 (Madison) Basic Travel Speed Statistics

Detection Type	Mean Speed	Standard Deviation	5th Percentile Speed	95th Percentile Speed	Minimum Speed	Maximum Speed
TomTom CTT	63.12	N/A	51.05	73.26	N/A	N/A
Bluetooth	68.05	4.22	61.88	73.33	17.65	96.59
NPMRDS	66.02	4.43	58.68	72.84	28.15	89.62
µWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A

Units are in miles per hour

Table 4.30. County M Basic Travel Speed Statistics

Detection Type	Mean Speed	Standard Deviation	5th Percentile Speed	95th Percentile Speed	Minimum Speed	Maximum Speed
TomTom CTT	48.07	N/A	39.55	56.86	N/A	N/A
Bluetooth	N/A	N/A	N/A	N/A	N/A	N/A
NPMRDS	47.49	10.49	24.84	59.58	1.24	72.83
µWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A

Units are in miles per hour

Table 4.31. US 14 (Janesville) Basic Travel Speed Statistics

Detection Type	Mean Speed	Standard Deviation	5th Percentile Speed	95th Percentile Speed	Minimum Speed	Maximum Speed
TomTom CTT	46.33	N/A	34.43	57.58	N/A	N/A
Bluetooth	51.25	8.06	35.70	59.06	13.41	99.47
NPMRDS	50.46	5.75	40.68	58.32	4.97	66.47
µWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A

Units are in miles per hour

Table 4.32. WIS 73 Basic Travel Speed Statistics

Detection Type	Mean Speed	Standard Deviation	5th Percentile Speed	95th Percentile Speed	Minimum Speed	Maximum Speed
TomTom CTT	44.05	N/A	31.74	56.69	N/A	N/A
Bluetooth	N/A	N/A	N/A	N/A	N/A	N/A
NPMRDS	34.11	15.24	9.69	56.37	1.24	68.90
µWave/Loop	60.87	6.37	48.60	67.64	1.86	74.94

Units are in miles per hour

Table 4.33. US 151 Basic Travel Speed Statistics

Detection Type	Mean Speed	Standard Deviation	5th Percentile Speed	95th Percentile Speed	Minimum Speed	Maximum Speed
TomTom CTT	24.45	N/A	17.27	34.72	N/A	N/A
Bluetooth	24.95	7.77	11.34	36.32	6.28	80.78
NPMRDS	27.61	6.22	17.19	37.00	1.24	64.36
µWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A

Units are in miles per hour

Table 4.34. I-39/90 Basic Travel Speed Statistics

Detection Type	Mean Speed	Standard Deviation	5th Percentile Speed	95th Percentile Speed	Minimum Speed	Maximum Speed
TomTom CTT	66.20	N/A	52.94	75.55	N/A	N/A
Bluetooth	62.75	6.95	48.56	69.33	24.76	98.39
NPMRDS	63.90	3.90	56.50	68.32	34.90	73.22
µWave/Loop	67.01	4.30	58.87	72.28	35.72	74.86

Units are in miles per hour

Table 4.35. US 12 Basic Travel Speed Statistics

Detection Type	Mean Speed	Standard Deviation	5th Percentile Speed	95th Percentile Speed	Minimum Speed	Maximum Speed
TomTom CTT	51.14	N/A	38.42	64.21	N/A	N/A
Bluetooth	52.89	15.31	23.85	73.70	14.48	99.85
NPMRDS	55.97	4.48	46.87	60.90	26.16	69.26
μWave/Loop	58.68	5.75	48.38	68.03	25.76	72.21

Units are in miles per hour

4.4.3. Detailed Statistics

The comparative statistics selected for use here are described briefly in this section and in more detail in the Analysis Plan and Literature Review. Detailed statistics include the following:

- ***Pairs*** – Observation matches between technologies for a given time period.
- ***Mean absolute error (MAE)*** – A basic indicator of the magnitude of the differences.
    - Note in the table that follows, that the data source shown in the first column will be the one with the higher average speed than the one in the second column.
- ***Root mean square error (RMSE)*** – RSME follows a similar pattern as MAE but provides an indication of the prevalence of occasional larger differences.
- ***Correlation coefficient (Corr)*** – The common Pearson correlation, indicating how substantial the linear relationship is between two sources relative to their means and variances. This ranges from 0 (no correlation) to 1 (perfect correlation).
- ***Theil's inequality coefficient (U)*** – A valuable measure of how closely paired time series observations align with one another. This ranges from 0 (perfect match) to 1 (no similar pattern). A key appeal of the coefficient U is that it can be decomposed into bias, variance, and covariance components. The following three components sum to one by definition.
- ***Bias proportion (Um)*** – Indicates the extent of systematic error, with values close to zero meaning little bias is evident.
- ***Variance proportion (Us)*** – Indicates how similarly varying the two sources are to one another, with values close to zero meaning each source provides data that varies as much as the other.
- ***Covariance proportion (Uc)*** – Measures unsystematic error. With travel time data, as speeds from one source decrease, speeds from the other source should also decrease.

Tables 4.36 through 4.42 show these detailed statistics for the travel time data, presented by route, except for County M which has no data to show.

Table 4.36. US 12/18 Detailed Travel Speed Statistics

Detection Type A	Detection Type B	Pairs	MAE	RSME	Corr	U	Um	Us	Uc
Bluetooth	NPMRDS	1,467	3.92	6.82	0.052	0.059	0.007	0.042	0.951
Bluetooth	μWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NPMRDS	μWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Units for MAE and RSME are in miles per hour while correlation and Thiel's coefficients are unitless

Table 4.37. US 14 (Madison) Detailed Travel Speed Statistics

Detection Type A	Detection Type B	Pairs	MAE	RSME	Corr	U	Um	Us	Uc
Bluetooth	NPMRDS	6,064	4.13	5.63	0.211	0.042	0.121	0.003	0.875
Bluetooth	µWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NPMRDS	µWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Units for MAE and RSME are in miles per hour while correlation and Thiel's coefficients are unitless

Table 4.38. US 14 (Janesville) Detailed Travel Speed Statistics

Detection Type A	Detection Type B	Pairs	MAE	RSME	Corr	U	Um	Us	Uc
Bluetooth	NPMRDS	2,644	6.25	9.61	0.054	0.094	0.015	0.048	0.937
Bluetooth	µWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NPMRDS	µWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Units for MAE and RSME are in miles per hour while correlation and Thiel's coefficients are unitless

Table 4.39. WIS 73 Detailed Travel Speed Statistics

Detection Type A	Detection Type B	Pairs	MAE	RSME	Corr	U	Um	Us	Uc
Bluetooth	NPMRDS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Bluetooth	µWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NPMRDS	µWave/Loop	2,071	26.42	30.72	0.030	0.313	0.793	0.091	0.116

Units for MAE and RSME are in miles per hour while correlation and Thiel's coefficients are unitless

Table 4.40. US 151 Detailed Travel Speed Statistics

Detection Type A	Detection Type B	Pairs	MAE	RSME	Corr	U	Um	Us	Uc
Bluetooth	NPMRDS	3,787	6.92	9.39	0.084	0.171	0.121	0.025	0.854
Bluetooth	µWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NPMRDS	µWave/Loop	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Units for MAE and RSME are in miles per hour while correlation and Thiel's coefficients are unitless

Table 4.41. I-39/90 Detailed Travel Speed Statistics

Detection Type A	Detection Type B	Pairs	MAE	RSME	Corr	U	Um	Us	Uc
Bluetooth	NPMRDS	11,804	3.72	5.68	0.602	0.045	0.045	0.523	0.432
Bluetooth	µWave/Loop	11,670	5.83	8.21	0.288	0.063	0.270	0.104	0.626
NPMRDS	µWave/Loop	11,770	4.17	5.35	0.434	0.041	0.327	0.075	0.598

Units for MAE and RSME are in miles per hour while correlation and Thiel's coefficients are unitless

Table 4.42. US 12 Detailed Travel Speed Statistics

Detection Type A	Detection Type B	Pairs	MAE	RSME	Corr	U	Um	Us	Uc
Bluetooth	NPMRDS	7,447	10.41	15.04	0.284	0.135	0.044	0.523	0.432
Bluetooth	µWave/Loop	7,819	10.97	16.01	0.240	0.140	0.131	0.356	0.513
NPMRDS	µWave/Loop	10,440	3.97	5.51	0.595	0.048	0.228	0.057	0.715

Units for MAE and RSME are in miles per hour while correlation and Thiel's coefficients are unitless

5. Cost Effectiveness Assessment

This section outlines the overall cost effectiveness for each of the travel time calculation methods outlined in the report. The sub-sections address the costs of each method, both initial and maintenance costs over the life of the equipment. The final section of the report combines this cost assessment with date quality to deliver the summary of which methods are most effective for various functional classifications of roadways.

5.1. Cost Information

The cost for each of the studied travel time technologies is addressed in this sub-section. It is important to note that these costs are estimates based on average values and do not include all specific project costs. In addition, these costs do assume certain default conditions, as any average values must. Costs vary for hardware installations based on the available communication infrastructure at the time of installation. For example, installation costs for microwave detection as shown in this section include the costs for all hardware structures associated with the detection unit, including mast and mounting hardware. However, mounting locations may be available if other ITS components or facilities are available.

For this reason, it is imperative that a true cost-benefit analysis be completed for any specific project and site. Using the numbers in this section is a useful starting point, but additional work must be done to consider the true costs for the project as the values in this section cannot replace such an analysis.

To compare the costs on an even scale, a ten-year deployment period is considered, with an assumed 3% discount to bring nominal costs back to current real net present costs (NPC). The NPC calculation equation is shown below for reference.

$$NPC = C_0 + \sum_{t=1}^{n} \frac{C_A}{(1+r)^t} + \frac{C_R}{(1+r)^n}$$

where NPC is Net Present Cost, dollars (present)
C_0 is initial cost, dollars (present)
C_A is annual cost, dollars (present)
C_R is replacement cost, dollars (present)
t is time period, years
n is number of periods, years
r is discount rate, unitless (percentage)

The sources for costs include WisDOT's traffic data collection matrix, which is a product that arose out of the TSMO-TIP project, past vendor prices, published resources from the I-95 Corridor Coalition, particularly for the TomTom costs, and the Federal Highway Administration's Intelligent Transportation Systems (ITS) Joint Program Office's costs database. Specific sources are reference in each detection type's cost section below.

5.2. Cost Summary

The origins of the cost for each travel time method differ significantly. When purchasing and using third-party probe data, the major costs are for software, including contracting the data and technical support. When deploying technologies such as Bluetooth detection, the major costs are for hardware, including hardware procurement, maintenance, and replacement.

The following generalizations can be made purely regarding costs of different travel time methods:

- Probe data are significantly less costly than methods where hardware must be deployed, especially for a large-scale deployment.
- If completing travel time calculations in a limited capacity, costs for most probe data versus Bluetooth detection are similar.
- With increasing number of miles for travel time deployments, all detection methods see decreases in cost per mile due to decreased cost of administration per unit.
- Deployments at a small scale are very expensive due to administrative costs.

Table 5.1 shows a summary of the costs per mile of each travel time deployment method for a 10-year deployment.

Table 5.1. Summary of Costs of Travel Time Deployment Methods

	TomTom	NPMRDS	Bluetooth	Microwave	Loop
Rural Freeway					
10 mi.	9.2	15.1	17.3	20.9	25.2
100 mi.	1.5	1.5	9.6	13.2	17.5
1000 mi.	0.6	0.2	8.8	12.4	16.7
Urban Freeway					
10 mi.	9.2	15.1	26.0	33.2	38.3
100 mi.	1.5	1.5	18.3	25.5	30.6
1000 mi.	0.6	0.2	17.5	24.7	29.9
Rural Arterial					
10 mi.	9.2	15.1	14.3	16.7	18.4
100 mi.	1.5	1.5	6.6	9.0	10.7
1000 mi.	0.6	0.2	5.8	8.2	10.0
Urban Arterial					
10 mi.	9.2	15.1	34.7	45.5	44.5
100 mi.	1.5	1.5	27.0	37.8	36.8
1000 mi.	0.6	0.2	26.2	37.0	36.0

Units: net present cost in thousands of dollars per mile, total for both directions

5.3. TomTom LTA/CTT

TomTom data are purchased directly through TomTom with data procurement and data servicing costs being the most significant. Procurement costs include contract development, invoicing, and attaining access to software. Data servicing costs include IT staff and consultant support services and updates to segment data occur several times per year and require IT integration hours. Data are purchased per-mile, so there is not a direct savings for deploying the technology over more miles, but generally there is a volume discount once a certain mileage purchase is reached (1000 miles is typical). Although additional routes require contract revisions and additional IT integration hours, economies of scale are still achieved in data integration and processing fees. Total estimated costs for a typical TomTom travel time deployment assuming no costs reductions are shown in Table 5.2.

Table 5.2. Cost Summary for TomTom Travel Time Deployment

	Initial Cost ($)	Annual Cost ($)	Replacement Cost ($)	10-Yr NPC ($)
Hardware	0	0	0	0.00
Software				
Travel Times (per mile)	0	62[13*]	0	529*
Data Management Fee	0	13[12*]	0	111*
Data Analysis	0	0	0	0
Data Integration	50000[14]	0	0	50000
IT/Processing/Maintenance	10000[15]	3000[14]	0	35591

*Costs are per mile

Total cost per mile: $640
Fixed costs: $ 128,242

Any Functional Class Roadway
Total cost per mile (10 miles): $9,199
Total cost per mile (100 miles): $1,496
Total cost per mile (1000 miles): $597

5.4. Bluetooth Reidentification

Bluetooth costs are shown for owned Bluetooth units, as these costs are generally less expensive than leasing units especially at a large scale. The most significant costs for using Bluetooth travel times include the hardware costs for Bluetooth units and replacement as well as the initial data integration costs. Software support is an annual cost that is contracted and includes IT, data management, and programming costs. Total estimated costs for a typical Bluetooth travel time deployment assuming no costs reductions (e.g., existing mounting hardware, volume purchase discounts, etc.) are shown in Table 5.3.

[13] TomTom's comparative pricing spreadsheet
[14] WisDOT's TomTom integration costs into the ATMS
[15] Estimates based on typical IT support for data technologies

Table 5.3. Cost Summary for Bluetooth Travel Time Deployment

	Initial Cost ($/unit)	Annual Cost ($/unit)	Replacement Cost ($/unit)	10-Yr NPC ($/unit)
Hardware				
Bluetooth Unit	4000[16]	0	4000[15]	6976
Installation	500[15]	0	500[15]	872
Power*	0	0	0	0
Backhaul	200[17]	20[16]	200[16]	519
Maintenance	0	100[16]	0	853
Software				
Data Analysis	0	420[16]	0	3583
Communications, cell	0	360[16]	0	3071
XML Feed	0	180[16]	0	1535
Data Integration (total)	50000[18]	0	0	50000
IT/Processing/Maintenance (total)	10000[17]	3000[17]	0	35591

*Solar powered and minimal power for communications

Total cost per unit: $17,410
Fixed costs: $85,591

Rural Freeway
Units per mile[19]: 0.5 per mile
Total cost per mile (10 miles): $17,264
Total cost per mile (100 miles): $9,562
Total cost per mile (1000 miles): $8,791

Urban Freeway
Units per mile[20]: 1 per mile
Total cost per mile (10 miles): $25,969
Total cost per mile (100 miles): $18,266
Total cost per mile (1000 miles): $17,495

Rural Arterial
Units per mile[21]: 0.33 per mile
Total cost per mile (10 miles): $14,304
Total cost per mile (100 miles): $6,601
Total cost per mile (1000 miles): $5,831

---

[16] Vehicle Detector Devices - Center for Transportation Research
[17] GLRTOC TAPCO pricing
[18] Estimates based on typical ATMS integration and IT support for data technologies
[19] Units per mile numbers are based on averages from highway types used in Wisconsin. These values are similar across Bluetooth detectors, microwave detectors, and inductive loops. Values for rural freeways range from 0.3 to 0.9 units per mile. Note that these are in units per mile, where a unit for a loop detector would include two loops per lane for each "unit." Bluetooth and microwave are based on one detector as a "unit." So for units per mile on a 10 mile rural freeway, you'd have 0.5 units per mile times 10 miles, or 5 units for that length of highway. This number obviously varies depending on interchange frequency and how "rural" the freeway really is, but these are the averages.
[20] Values for urban freeways range from 0.9 to 1.5 units per mile.
[21] Values for rural arterials range from 0.2 to 0.4 units per mile.

Urban Arterial
Units per mile[22]: 1.5 per mile
Total cost per mile (10 miles): $34,674
Total cost per mile (100 miles): $26,971
Total cost per mile (1000 miles): $26,200

5.5. NPMRDS

Travel times from NPMRDS are not available real-time, only upon monthly updates. While valuable for many applications, this source is not comparable to other sources in this analysis. Nonetheless, it is included for comparison purposes as the data may replace certain deployments in place for historical reporting purposes, or it may be necessary to compare these costs in justification documents

NPMRDS data are provided for free to state DOTs though a USDOT contract. Thus, the primary costs are for data integration and IT. Note, these costs factor in changing of data providers by USDOT, which would incur additional data integration costs and these are factored in as replacement costs. The most significant costs for using NPMRDS travel times include the high cost of data analysis which requires technical support as well as the initial data integration costs. Because incremental hardware costs are minimal, cost per mile decreases significantly with miles used for this service. Total estimated costs for a typical NPMRDS travel time deployment assuming no cost reductions are shown in Table 5.4.

Table 5.4. Cost Summary for NPMRDS Travel Time Deployment

	Initial Cost ($)	Annual Cost ($)	Replacement Cost ($)	10-Yr NPC ($)
Hardware	0	0	0	0
Software				
Data Analysis	0	5000[23]	0	42651
Data Integration	50000[24]	0	25000[23]	68602
IT/Processing/Maintenance	10000[23]	3000[23]	5000[23]	39311

Fixed costs: $ 150,564

Any Functional Class Roadway
Total cost per mile (10 miles): $15,056
Total cost per mile (100 miles): $1,506
Total cost per mile (1000 miles): $151

[22] Values for urban arterials range from 1.0 to 2.0 units per mile.
[23] Estimates based on typical data processing efforts for NPMRDS
[24] Estimates based on typical ATMS integration and IT support for data technologies

5.6. Microwave Radar

The most significant costs for using microwave travel times include the hardware costs for microwave units and replacement as well as the initial data integration costs. Total estimated costs for a typical microwave detector travel time deployment assuming no costs reductions are shown in Table 5.5.

Table 5.5. Cost Summary for Microwave Detector Travel Time Deployment

	Initial Cost ($/unit)	Annual Cost ($/unit)	Replacement Cost ($/unit)	10-Yr NPC ($/unit)
Hardware				
Microwave Unit	5500[25]	0	5500[24]	9593
Installation	5000[24]	0	500[24]	5372
Power	0	10	0	85
Backhaul	200[26]	20[25]	200[25]	519
Maintenance	0	100	0	853
Software				
Data Analysis	0	420[25]	0	3583
Communications, cell	0	360[25]	0	3071
XML Feed	0	180[25]	0	1535
Data Integration (total)	50000[27]	0	0	50000
IT/Processing/Maintenance (total)	10000[26]	3000[26]	0	35591

Total cost per unit: $24,611
Fixed costs: $85,591

Rural Freeway
Units per mile: 0.5 per mile
Total cost per mile (10 miles): $20,865
Total cost per mile (100 miles): $13,162
Total cost per mile (1000 miles): $12,391

Urban Freeway
Units per mile: 1 per mile
Total cost per mile (10 miles): $33,170
Total cost per mile (100 miles): $25,467
Total cost per mile (1000 miles): $24,697

Rural Arterial
Units per mile: 0.33 per mile
Total cost per mile (10 miles): $16,681
Total cost per mile (100 miles): $8,977
Total cost per mile (1000 miles): $8,207

[25] Data from Wavetronix and International Road Dynamics, Inc. using Final Report on Rapidly Deployable Low-Cost Traffic Data and Video Collection Device
[26] GLRTOC TAPCO pricing
[27] Estimates based on typical ATMS integration and IT support for data technologies

Urban Arterial
Units per mile: 1.5 per mile
Total cost per mile (10 miles): $45,476
Total cost per mile (100 miles): $37,773
Total cost per mile (1000 miles): $37,003

5.7. Inductive Loops

Although WisDOT typically has installed loops only for stop bar detection in the past 15 years, this section is included for comparison to allow for a full cost-benefit comparison between travel time detection types.

The most significant costs for using loop travel times include the hardware costs for loop units, especially as number of lanes increases. Total estimated costs for a typical loop detector travel time deployment assuming no cost reductions are shown in Table 5.6.

Table 5.6. Cost Summary for Loop Detector Travel Time Deployment

	Initial Cost ($/unit)	Annual Cost ($/unit)	Replacement Cost ($/unit)	10-Yr NPC ($/unit)
Hardware				
Loop Detector (per lane)	500[28]	0	500[27]	872
Support Hardware	5000[27]	0	5000[27]	8720
Installation	500[27]	0	500[27]	872
Power	0	20[27]	0	171
Backhaul	200[29]	20[28]	200[28]	519
Maintenance	0	100[28]	0	853
Software				
Data Analysis	0	420[28]	0	3587
Communications, cell	0	360[28]	0	3071
XML Feed	0	180[28]	0	1535
Data Integration (total)	50000[30]	0	0	50000
IT/Processing/Maintenance (total)	10000[29]	3000[29]	0	35591

Total cost per lane: $872
Total cost per unit: $19,325
Fixed costs: $85,591

Rural Freeway (4 lanes, dual-detector)
Units per mile: 0.5 per mile
Total cost per mile (10 miles): $25,198
Total cost per mile (100 miles): $17,495
Total cost per mile (1000 miles): $16,724

---

[28] Intelligent Transportation Systems Benefits, Costs, Deployment, and Lessons Learned Desk Reference
[29] GLRTOC TAPCO pricing
[30] Estimates based on typical ATMS integration and IT support for data technologies

Urban Freeway (6 lanes, dual-detector)
Units per mile: 1 per mile
Total cost per mile (10 miles): $38,348
Total cost per mile (100 miles): $30,645
Total cost per mile (1000 miles): $29,875

Rural Arterial (2 lanes, dual-detector)
Units per mile: 0.33 per mile
Total cost per mile (10 miles): $18,424
Total cost per mile (100 miles): $10,721
Total cost per mile (1000 miles): $9,951

Urban Arterial (4 lanes, dual-detector)
Units per mile: 1.5 per mile
Total cost per mile (10 miles): $44,522
Total cost per mile (100 miles): $36,819
Total cost per mile (1000 miles): $36,049

6. Conclusions and Recommendations

This section summarizes the results of the study, presents conclusions based on those results (Section 6.1), and offers recommendations for consideration (Section 6.2).

Results were determined in this study for a variety of travel time technology topics related to the successful delivery of travel times from a comprehensive perspective, from technology installation, maintenance, and replacement to communication of travel times and efficacy of these travel times. This provides for the basis of a cost-benefit analysis procedure by comparing the different technologies. This is not meant to supersede an in-depth analysis needed for a specific project, however the data in this report can support such an analysis.

The objectives of the T3E project were 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 among competing technologies,
- compare difficulty of accessing and processing data sources,
- determine other uses of travel time data, and
- integrate technologies into the transportation systems management and operations (TSM&O) decision process for detection.

The results for the first two objectives are discussed in Section 6.1. The third item is reviewed in detail in Section 2, while the fourth is reviewed in Section 3. The last two items are discussed as part of the recommendations in Section 6.2.

6.1. T3E Project Conclusions

Conclusions are presented in terms of data quality versus cost and overall rankings by type of facility and term of travel time deployment. Section 2 of this report outlined many elements of data quality including access, latency, reliability, archiving, and durability. Section 3 reported on data quality in terms of data processing, availability of observations, and travel time availability. Section 3 summarized elements of the quality of the travel times reported, including travel time accuracy and consistency using statistical analysis. Section 5 looked at the other side of the coin, the costs of initiating a travel time deployment and the maintenance and replacement costs associated with supporting such a deployment for each technology.

All of this work is combined and summarized in this section to provide a comprehensive view of the strengths and weaknesses of the technologies available. For specific details about each technology for a given topic, refer to the appropriate subsection of Sections 2-5 of this report. Table 6.1 shows an overall comparison of each travel time detection technology considered in this report. Each technology is given a 1-5 ranking across 13 of the topics discussed throughout this report. A score of 1 being lowest performance (least benefit or highest cost) and a score of 5 being highest performance (greatest benefit or lowest cost). This is not a ranking of the different technologies, in that they are not ranked from 1 to 5. Multiple technologies can receive the same score, as these are based on overall performance. For instance, the durability score for TomTom and NPMRDS are both 5 because there is no hardware involved and thus they offer a durable solution. These scores are taken from a qualitative review of the results of Sections 2-5 so they should be taken as suggestions with reference to the material in those sections, rather than precise values.

This table can be used to quickly review and compare technologies on these different focus areas. The table also offers an average of these scores for benefits and costs, as well as an overall average which is a simple average of the overall benefit and cost averages. Again, these numbers should be considered as a starting point for analysis, recognizing the pros and cons vary by the nature of the deployment or application.

Table 6.1. Cost-Benefit Comparison of Travel Time Technologies Used in this Study

	TomTom (CTT)	NPMRDS	Bluetooth	Microwave	Loop
Benefits					
Access	2	5	3	4	4
Latency	3	1	2	4	4
Reliability	2	2	2	3	4
Archiving	2	4	3	5	5
Durability	5	5	2	3	4
Processing	1	5	4	4	4
Available Observations	1	1	2	4	5
Travel Time Availability	4	1	4	4	4
Travel Time Accuracy	4	4	4	4	4
Travel Time Consistency	4	4	4	4	4
Costs					
Initial Cost	4	5	3	2	4
Annual Cost	1	5	2	4	4
Replacement Cost	5	5	3	3	4
Averages					
Benefits	2.8	5.0	3.0	3.9	4.2
Costs	3.3	5.0[31]	2.7	3.0	4.0
Overall	3.1	4.1[17]	2.8	3.5	4.1

[31] Though NPMRDS receives the best cost score, its benefits are actually lower than shown because data are not real-time. For most other applications requiring historic travel times, it is the best option.

Table 6.2 shows a recommended list of technologies to consider in order for a specific deployment strategy. This table is not meant as a hard ranking to offer which exact technology in which situation, but as a guide on which technologies tend to work best in a given deployment strategy. Comparisons are offered for specific applications of technology including arterial versus freeway, rural versus urban, and long-term versus short-term installations.

To be clear, the table is not meant to authoritatively state which technology to use in a given situation, but instead offer a guide as to which technologies typically function best and should be pursued first. For instance, if working on a temporary deployment for a small-scale rural project on an arterial, Bluetooth technology should be considered first.

Table 6.2. Overall Comparison of Travel Time Technologies by Facility Type

	Data Quality				Cost			Overall
Facility Type	**Reliability**	**Availability**	**Latency**	**Accuracy**	**Initial (Integration, Acquisition, Processing)**	**Lifecycle (Maintenance, Data Storage, Fees)**	**Replacement**	
Rural Freeway, Temporary	1. Lp 2. µW 3. TT 4. BT	1. Lp 2. µW 3. BT 4. TT	1. Lp 2. µW 3. TT 4. BT	1. TT 2. BT 3. µW 3. Lp	1. BT 2. µW 3. Lp 4. TT	1. BT 2. µW 3. Lp 4. TT	1. TT 2. BT 3. Lp 4. µW	1. BT 2. µW 3. Lp 4. TT
Rural Freeway, Permanent	1. Lp 2. µW 3. TT 4. BT	1. Lp 2. µW 3. BT 4. TT	1. Lp 2. µW 3. TT 4. BT	1. TT 2. BT 3. µW 3. Lp	1. Lp 2. TT 3. BT 4. µW	1. Lp 2. BT 3. µW 4. TT	1. TT 2. BT 3. Lp 4. µW	1. Lp 2. TT 3. µW 4. BT
Urban Freeway, Temporary	1. Lp 2. µW 3. TT 4. BT	1. Lp 2. µW 3. BT 4. TT	1. Lp 2. µW 3. TT 4. BT	1. TT 2. BT 3. µW 3. Lp	1. BT 2. µW 3. Lp 4. TT	1. BT 2. µW 3. Lp 4. TT	1. TT 2. BT 3. Lp 4. µW	1. BT 2. µW 3. Lp 4. TT
Urban Freeway, Permanent	1. Lp 2. µW 3. TT 4. BT	1. Lp 2. µW 3. BT 4. TT	1. Lp 2. µW 3. TT 4. BT	1. TT 2. BT 3. µW 3. Lp	1. Lp 2. TT 3. BT 4. µW	1. Lp 2. BT 3. µW 4. TT	1. TT 2. BT 3. Lp 4. µW	1. Lp 2. TT 3. µW 4. BT
Rural Arterial, Temporary	1. Lp 2. µW 3. BT 4. TT	1. Lp 2. µW 3. TT 4. BT	1. Lp 2. µW 3. TT 4. BT	1. TT 2. BT 3. µW 3. Lp	1. BT 2. µW 3. Lp 4. TT	1. BT 2. µW 3. Lp 4. TT	1. TT 2. BT 3. Lp 4. µW	1. BT 2. µW 3. Lp 4. TT
Rural Arterial, Permanent	1. Lp 2. µW 3. BT 4. TT	1. Lp 2. µW 3. TT 4. BT	1. Lp 2. µW 3. TT 4. BT	1. TT 2. BT 3. µW 3. Lp	1. Lp 2. TT 3. BT 4. µW	1. Lp 2. BT 3. µW 4. TT	1. TT 2. BT 3. Lp 4. µW	1. Lp 2. TT 3. µW 4. BT
Urban Arterial, Temporary	1. Lp 2. µW 3. BT 4. TT	1. Lp 2. µW 3. TT 4. BT	1. Lp 2. µW 3. TT 4. BT	1. TT 2. BT 3. µW 3. Lp	1. BT 2. µW 3. Lp 4. TT	1. BT 2. µW 3. Lp 4. TT	1. TT 2. BT 3. Lp 4. µW	1. BT 2. µW 3. Lp 4. TT
Urban Arterial, Permanent	1. Lp 2. µW 3. BT 4. TT	1. Lp 2. µW 3. TT 4. BT	1. Lp 2. µW 3. TT 4. BT	1. TT 2. BT 3. µW 3. Lp	1. Lp 2. TT 3. BT 4. µW	1. Lp 2. BT 3. µW 4. TT	1. TT 2. BT 3. Lp 4. µW	1. Lp 2. TT 3. µW 4. BT

Overall analysis based report results summarized in these tables offers a few key takeaways.

The major takeaway from this study is that all travel time technologies are reasonably accurate for most routes and there is no definitive answer across the board on which technology should be used. The answer varies based on need for the current project and current assets available. This report offers more tools to being to address these questions.

Some specific examples are included here. First, for a temporary deployment such as a short term construction project, where a TomTom contract is not in place on the route, Bluetooth or microwave detectors can offer a quick solution that is effective and accurate. If a TomTom contract is in place, such as the example of data provided for the Verona Road project, exclusively using TomTom will be the least expensive option, with verifications performed as needed to verify accurate travel times. For a permanent, small-scale deployment on a freeway, loops or microwaves offer the better solution.

For wide-spread, permanent deployments, such as those on a state-wide basis (such as a deployment on the entire NHS), the economies of scale offered by TomTom make it the clear solution. This is due to the lack of hardware maintenance, the lack of need to add fiber or wireless connectivity, and the ability of TomTom travel times to be accurate even with very low match percentages.

Again, these recommendations are a good starting point, but more in depth analysis should be performed for each specific application of travel times for a new route.

6.2. T3E Project Recommendations

In addition to the conclusions offered in Section 6.1, this section seeks to discuss recommendations for future work and research in order to get a clearer picture of how to best use travel times to provide accurate and timely results in real-time, and to provide the most accurate times in historical applications. The following recommendations are offered.

Work with a variety of third-party probe data providers to secure the best price.

All provider's technologies are becoming more mature, offering better observation percentages across all routes and times of day. As more and more vehicles are equipped with probe devices and people bring probe devices into vehicles, these sources will only improve. Most of the providers, including TomTom, INRIX, and HERE, offer similarly effective travel times with varying pros and cons, so working with all providers to increase coverage and reduce price is recommended.

Study specific traffic events to get a better picture about latency.

A limitation for this study is that average travel times and speeds were calculated over months instead of looking at specific events. Although these were calculated by segment and by time period, a single traffic-slowing event is likely lost in the average. Therefore, it is recommended that an additional study be done looking at specific events on one or two routes where traffic was slowed for some reason, such as road construction or a crash. This will help determine how truly effective these travel time detection methods are. For instance, lag can be determined as to how soon an event is detected, and how long after return to free-flow speed it takes for the detection method to follow. A rural freeway and an urban principal arterial with many signalized intersections would both be interesting to study in more detail.

Study TomTom data more precisely to determine true travel time availability percentages.

Another limitation of this study was that of the statistical analysis of TomTom data. Being TomTom data are costly to process as small intervals, doing a detailed statistical comparison was not possible for this project. Doing this analysis on a small enough scale that would be manageable versus number of credits used. Comparing a small set of LTA data to CTT data would also be desirable.

Study reported travel times as compared to travel times from the technologies in this study.

This study did not look at the aggregated and processed values for travel times as reported through the XML feed and via Wisconsin 511. A future study doing this comparison would help better compare travel time accuracy between detection types. WisTransPortal currently has an archived travel time downloader tool in test phase that could be used for this study. This project could be coupled to the latency study as well.

Be prepared to transition travel time messages to other technologies.

Displaying travel times on DMS is currently an important means of providing travelers with real-time traffic data. However, many drivers are turning to in-vehicle applications such as Waze for their travel navigation purposes based on current travel times. DOTs need to be prepared to offer travel times to in-vehicle displays and to integrate these travel times with other technologies.

Integrate technologies into the TSM&O Traffic Infrastructure Process (TSMO-TIP).

The TSMO-TIP offers a well-defined process for evaluating and deploying technologies for a given project. Therefore it is recommended that the decision for which travel time deployment technology on a route be integrated into this process. This will make selection more consistent with other ITS devices and allow for more agility with rapid changes to technologies.

Continue to monitor connected vehicles (CVs) as an option for calculating Travel Times.

Connected vehicle technologies are advancing quickly and infrastructure for vehicle-to-infrastructure (V2I) communications is beginning to be installed across the country, including in Madison, Wisconsin. As more of this technology becomes available and more vehicles are equipped with this technology, CVs could become a viable alternative to other travel time detection methods.

References

OpenLR White Paper, Version 1.5 Revision 2. TomTom International B.V., 2009-2012. < http://www.openlr.info/data/docs/OpenLR-Whitepaper_v1.5.pdf >

Transportation Systems Management and Operations Traffic Infrastructure Process (TSMO-TIP). Project Documentation. < http://www.topslab.wisc.edu/tsmo/tip/>

Rafferty, P., Jin, J., and Francour, A. GLRTOC Comments on MAP-21 NPRM for Part 490, National Performance Management Measures. August 2016. < http://www.glrtoc.org/documents/2016/08/map-21-system-performance-nprm-comments.pdf>

TomTom Comparative Prices Spreadsheet for Third Party Probe Data Providers. Version 19.

Machemehl, R., Motamed, M. Vehicle Detector Devices. Center for Transportation Research. University of Texas at Austin. 2012. < https://library.ctr.utexas.edu/ctr-publications/misc/machemehl-vehicledetectordevices.pdf

Schwach, J.A., Morris, T., and Michalopoulos, P.G., Rapidly Deployable Low-Cost Traffic Data and Video Collection Device. ITS Institute. University of Minnesota. December 2009. < http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.542.7801&rep=rep1&type=pdf>

National Connected Vehicle Field Infrastructure Footprint Analysis. Final Report. ITS Joint Program Office. U.S. Department of Transportation. June 27, 2014. <https://ntl.bts.gov/lib/52000/52600/52602/FHWA-JPO-14-125_v2.pdf>

Intelligent Transportation Systems Benefits, Costs, Deployment, and Lessons Learned Desk Reference. 2014 Update. . ITS Joint Program Office. U.S. Department of Transportation. 2014. < http://www.itsknowledgeresources.its.dot.gov/its/bcllupdate/pdf/BCLL_2014_Combined_JPO-FINAL.pdf>

ISO 8601:2004. Data elements and interchange formats -- Information interchange -- Representation of dates and times. International Organization for Standardization. Dec., 2004.

Google Protocol Buffers Documentation. < https://developers.google.com/protocol-buffers/>

Record Editor Protocol Buffers Message Editor Introduction <http://record-editor.sourceforge.net/ProtoBufIntro.htm>

Note: Additional References included at end of Literature Review

Appendix A. TomTom LTA Data Development

This appendix explains the process of using TomTom Live Traffic Archive (LTA) data. LTA data include archived real-time traffic flow and incident information.

The procedure is cumbersome and involves significant computer programming knowledge and the use of many applications. In this project, a number of automation algorithms were written or theorized to make this process easier and more efficient. For those who have a computer programming background, this section serves as a primer for accessing and working with LTA data.

Section A.1 describes the process of acquiring data from the online interface. Section A.2 then shows the steps to decode the data using a protocol buffer (ProtoBuf) reader. Once these data are accessed, the location of each link needs to be decoded using TomTom's open dynamic location referencing protocol, OpenLR. The decoding process is described in Section A.3. Finally, data can be shown in a map format for easy viewing. Section A.4 shows the procedure for creating an ArcGIS shapefile to be used in mapping efforts. Section A.5 discusses automation of the procedure and next steps to improve LTA data processing.

A.1. Data Access

TomTom Live Traffic Archive data are available for one minute intervals and are downloaded for the entire state. Available data for each segment-interval include location, speed, travel time, and confidence interval.

The download screen (Figure A.1) allows for selection of the data, hour, and minute range. This makes downloading large ranges of data difficult. For this reason, a data downloader was developed as part of this project using Python and packages including Selenium and ChromeDriver. Using this software, TOPS built and maintains an archive of all data for research purposes from April 14, 2015 through August 31, 2017. This software and the data are maintained by TOPS Lab and available upon request.

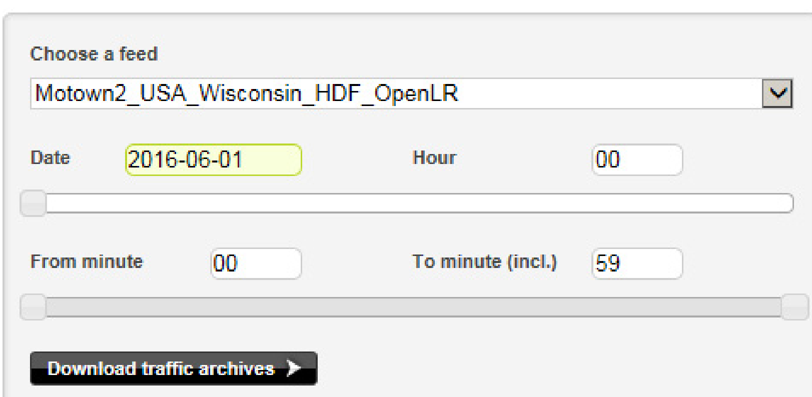


Figure A.1. Data Access Screen for TomTom Live Traffic Archive Tool

The file downloaded for each one-hour period is a zip file of roughly 45 megabytes. Unzipping this file will produce a folder of roughly 80 megabytes, including 60 files, one for each minute during the hour selected. These files do not have an extension making file type difficult to determine without prior knowledge. The files are all in protocol buffer binary file format and decoding of this format is discussed in the next section. The file names are in ISO 8601 format.[32] The specific format is YYYY-MM-DDThh:mm:ssZ, where YYYY is the four-digit year, MM is the two-digit month, DD is the two-digit date, T is a delimiter designating time as the next value, hh is the two-digit hour, mm is the two-digit minute, ss is the two-digit second (meaningless for this data), and Z is the standard time zone which is zero offset from coordinated universal time (UTC). Central Standard Time (CST) is six hours behind UTC and Central Daylight Time is five hours behind UTC. In the unzipped folder, the colons are replaced with underscores in most operating systems (e.g., 2016-08-16T18_15_38Z).

A.2. Data Decoding

In order to open a TomTom LTA file, a protocol buffer reader must be used. Protocol buffers are a Google data structure similar to extensible markup language (XML).[33] The file is essentially an encoded data structure that requires a ".proto" file to decode. This file was provided by TomTom to both WisDOT and TOPS. Although data can be decoded from an encoded protocol buffer file with any programming language, pre-written decoding software makes viewing files much easier. For this project, an open source editor called Record Editor ProtoBuf Editor was used.[34] A screenshot of the editor menu is shown in Figure A.2 and a screenshot of an example record is shown in Figure A.3.

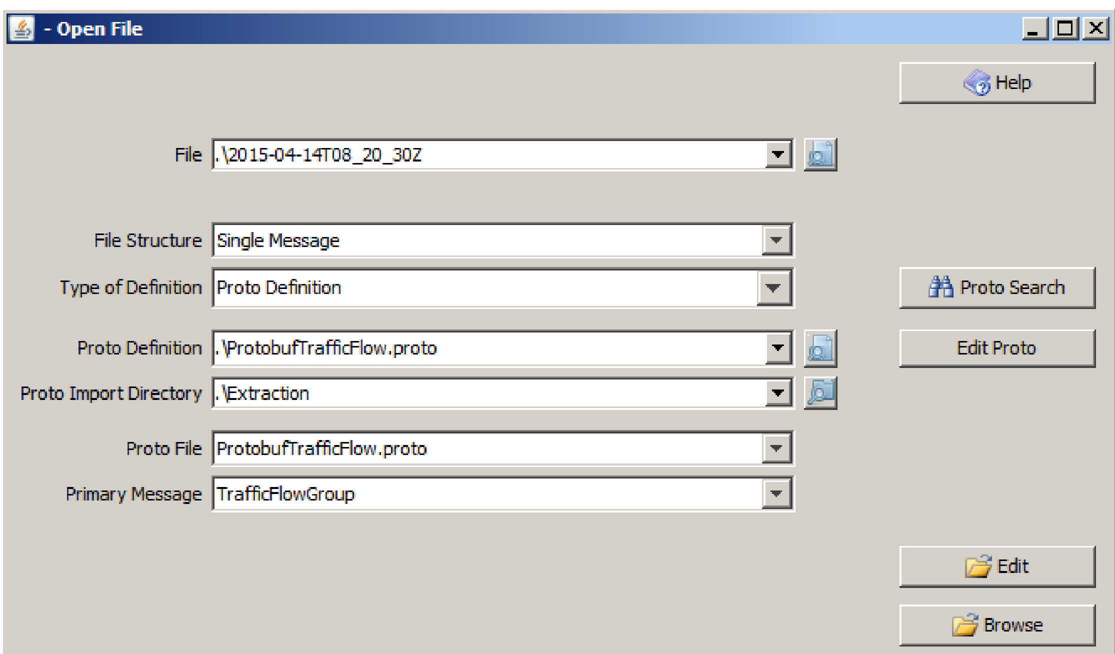


Figure A.2. Screenshot of Record Editor ProtoBuf Editor Open File Dialog Box

[32] ISO 8601:2004
[33] Google Protocol Buffers Documentation
[34] Record Editor ProtoBuf Reader Documentation

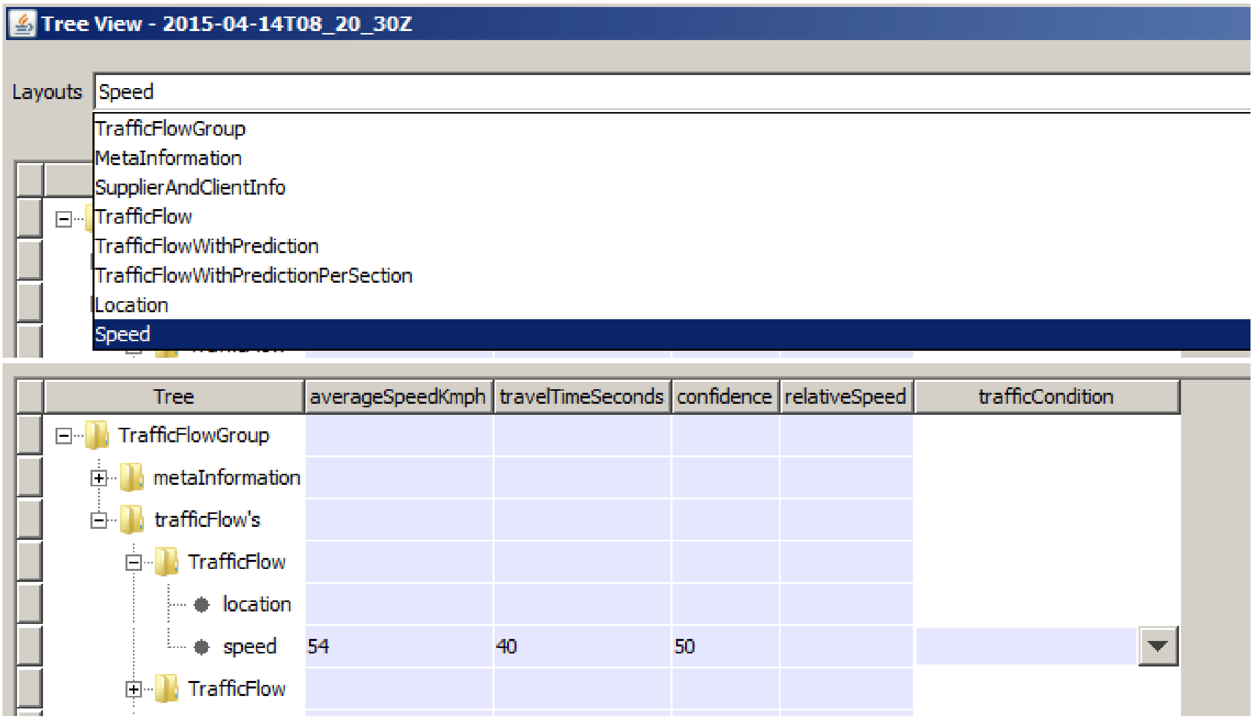


Figure A.3. Screenshot of Record Editor ProtoBuf Editor TomTom File View – Speed

Note in Figure A.3 that the confidence interval is shown as 50. This seems very prevalent in most of the files. Also note that location is not shown. Location must first be selected in the drop down menu and then in the file. This is a limitation of the Record Editor software and not the TomTom file itself. An example location is shown in Figure A.4. The Record Editor software allows the file to be extracted in full to a CSV file for easy access to all data at once. This process can be automated for all files of interest.

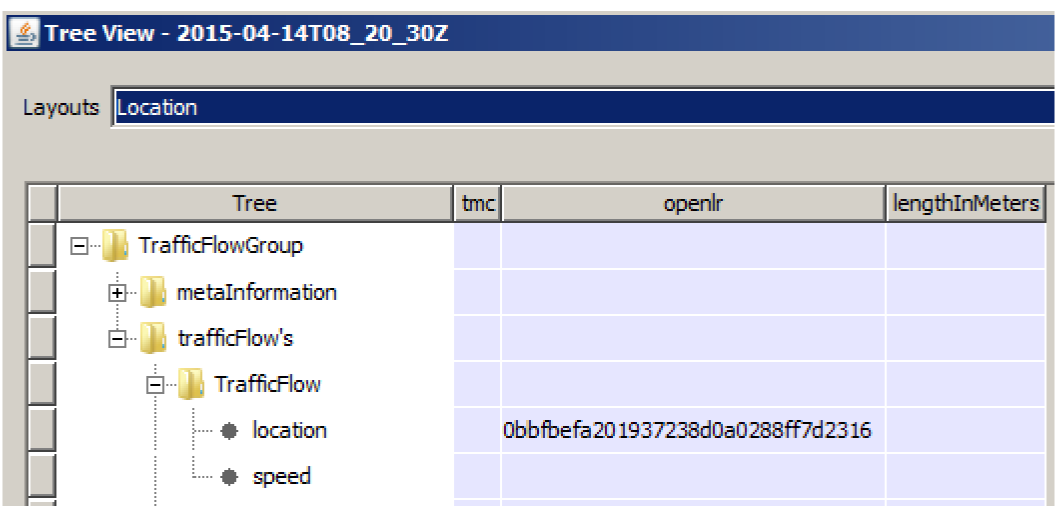


Figure A.4. Screenshot of Record Editor ProtoBuf Editor TomTom File View – Location

A.3. Link Decoding

Once files are stored, all information is available for each segment. However, each segment is encoded by a unique OpenLR hexadecimal (hex) string. A road segment as defined by OpenLR is given by a start point and an end point (with optional intermediate points).
The format of the OpenLR string can depends on the number of reference points used for a road segment, with a minimum of two points required. A location reference given by two points will have an OpenLR string between 16 and 18 bytes (32 and 36 hex values). Each added reference point adds 7 bytes (14 hex values) to the string. There are also other formats that are described in the OpenLR white paper.[35] Typically, most road segments are provided with only two points.

The general format of a two location reference point OpenLR string consists of the following 18 bytes shown in Table A.1.

Table A.1. OpenLR Data Format for a Segment with Two Location Reference Points

Byte Range	Data Stored in Byte(s)
1	Status (includes information on what type of OpenLR string follows)
2-4	Longitude of starting point of segment (high, middle, and low byte)
5-7	Latitude of starting point of segment (high, middle, and low byte)
8-10	Attributes of the roadway including functional class
11-12	Relative longitude to end point of segment (high and low byte)
13-14	Relative latitude to end point of segment (high and low byte)
15-16	Additional attributes of the roadway
17-18	Positive and negative offset (optional)

Although all values can be used in decoding, the most important values are the latitude and longitude of the starting point and the relative latitude and longitudes to the end point. With these, the location of a segment can be determined.

An example OpenLR hexadecimal string is: 0x0BBFBEFA201937238D0A0288FF7D2316

From this, the latitudes and longitudes can be extracted and placed into binary twos-complement form which can be translated into an integer, as shown in Table A.2.

Table A.2. Decoding Latitude and Longitude Points of Example into Integer Form

Value	Bytes	Hexadecimal	Binary (Two's Compliment)	Integer
Longitude of starting point	3	0xBFBEFA	101111111011111011010100	-4210988
Latitude of starting point	3	0x201937	000111110000011001110011	2033267
Relative Longitude to end point	2	0x0288	0000001001101000	616
Relative Latitude to end point	2	0xFF7D	0000011101101011	1899

[35] OpenLR White Paper

Once integer values are found, the following equation is used to determine the decimal degrees for the starting point latitude and longitude values:

$$D = \frac{(I - sign(I) \cdot 0.5) \cdot 360}{2^r}$$

where D is latitude or longitude value, decimal degrees
sign is 1 for positive integer, -1 for negative integer
I is integer value, unitless
r is resolution, decimeters (Default is 24)

Applying this equation to the starting point integers from Table A.2, the latitude/longitude of the starting point in this example is 43.6292, -90.3580 which is on WIS 80 at the intersection with River Road south of Hillsboro in Vernon County.

The relative offset values are determined using the following equation:

$$D_N = D_O + \frac{R}{10^5}$$

where D_N is latitude or longitude of next point, decimal degrees
D_O is latitude or longitude of origin point, decimal degrees
R is relative offset, unitless

Applying this equation to the relative point integers from Table A.2, the latitude/longitude of the ending point in this example is 43.6482, -90.3518 which is on WIS 80, as expected, at the intersection with Vernon County Q just west of Hillsboro. When these latitude/longitude pairs are typed into Google's directions service, the 1.5 mile segment of WIS 80 southwest of Hillsboro is displayed, as shown in Figure A.5.

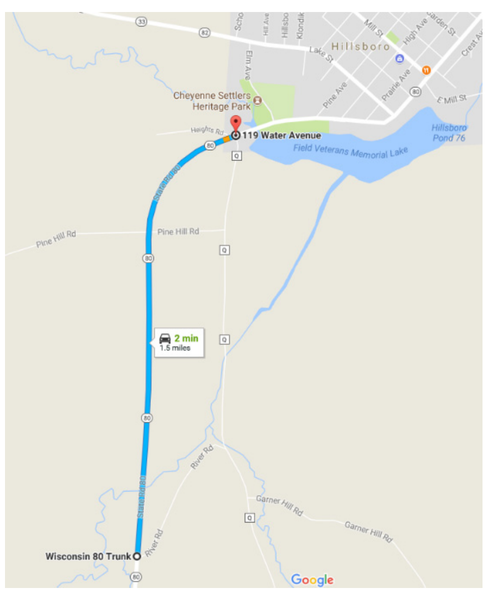


Figure A.5. Decoded OpenLR Segment for 0x0BBFBEFA201937238D0A0288FF7D2316

A.4. Shapefile Creation

The dilemma with only having two points to determine a segment is that two points define a straight line, while most segments are not straight lines (e.g., Figure A.5 example). There are multiple ways to map the two points to the correct geometry, but all involve the use of prior line segments having already been determined.

To get an exact line, the method of entering points into Google Maps can be used through the Google Maps application programming interface (API). Once there, the segment can be extracted with KML and converted to a shapefile or other format.

However, this method is not as useful when trying to match the segment to a segment on the state trunk network (STN) used in WisDOT's Meta-Manager. To do this, an algorithm was written to match the segment start and end points with the best fitting STN segment. This program was completed in beta form, and successfully proved the concept.

A.5. Automation and Next Steps

This section described initial methods to access, process, and display data from TomTom's LTA tool. These algorithms are a good start, but fully automating the process is clearly needed if LTA data are going to be of value to WisDOT.

In order to fully automate the process, the algorithms need to be combined into a web interface or application that streamlines the process. The final product should accept date and time ranges as well as segments of interest. The application should then do all of the processing on the back end and provide back a shapefile and/or online map that displays the data on the STN.

With the work done for this project, TOPS Lab now has the knowledge and skills required to complete such an application and could do so on a future project.

Appendix B. Analysis Plan

Attached as Pages B-1 through B-23.

Appendix C. Literature Review

Attached as Pages C-1 through C-14.

Wisconsin DOT Travel Time Technology Evaluation (T3E)

Analysis Plan

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

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
Master Contract Number: 0072-39-25
Work Order Number: 9.30
DTSD Big Ticket Number: BTO18
Object Code: 5501
Funding Appropriation: 365 – Highway system management and operations

Table of Contents

List of Figures

List of Tables

B-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 C.

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 B-A for the project management timeline for this project.

B-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.

B-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.

B-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.

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

Table B-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 B-3)	Average	Varies by site (see Table B-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

B-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.

B-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.

B-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.

B-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.

B-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.

B-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.

B-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.

B-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.

B-3. Study Area and Period

B-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)

B-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 B-3 and Figure B-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 B-1 with a circle, as the route is short and difficult to see.

Table B-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

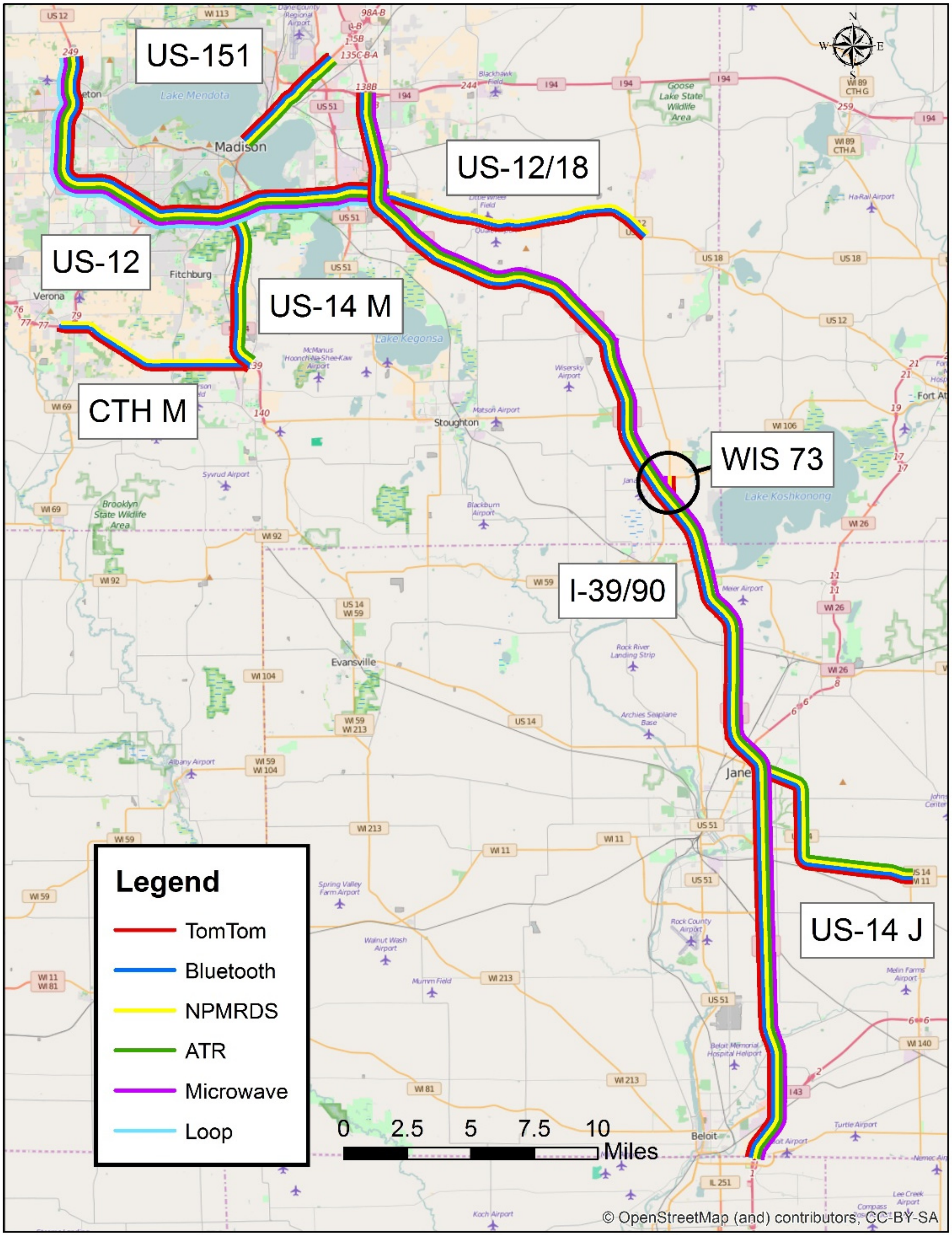


Figure B-1. Travel Time Technology Evaluation (T3E) Route Overview Map

B-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 B-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 B-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

B-4. Analysis Steps

B-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 B-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.

B-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 B-2

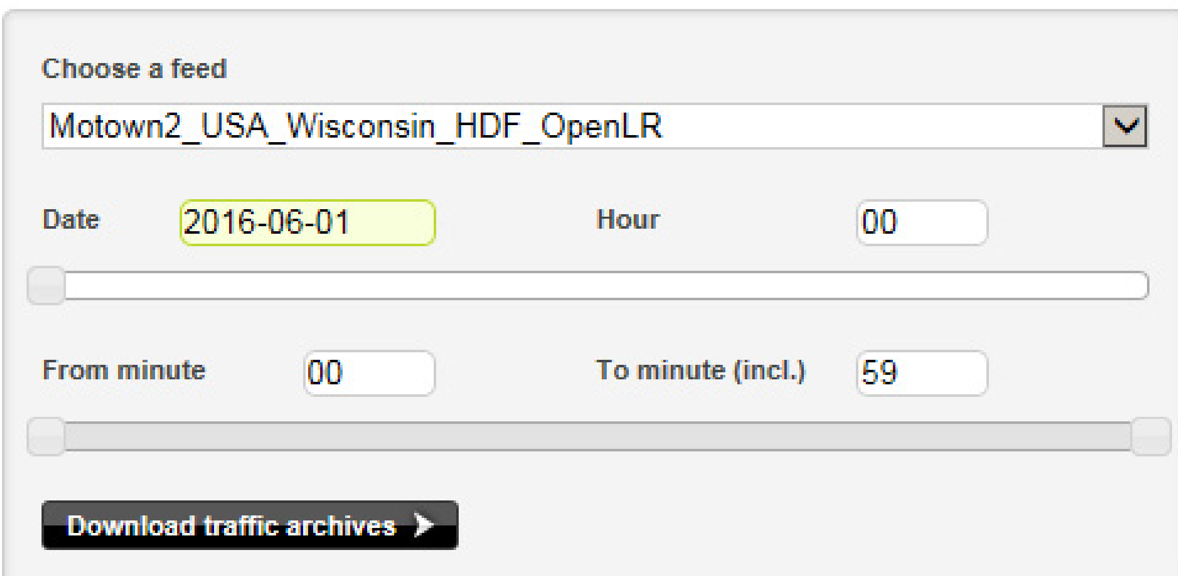


Figure B-2. Data Access Screen for TomTom Live Traffic Archive Tool

B-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 B-3, B-4, and B-5

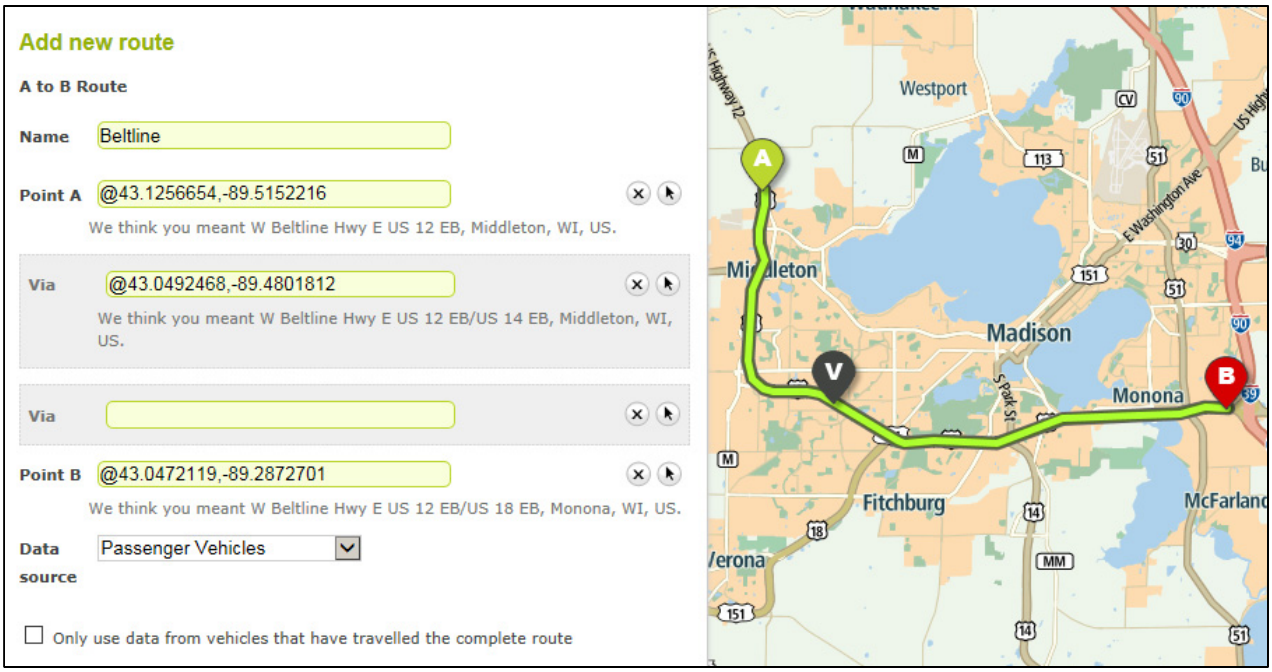


Figure B-3. Data Access Screen (Routes) for TomTom Custom Travel Time Tool

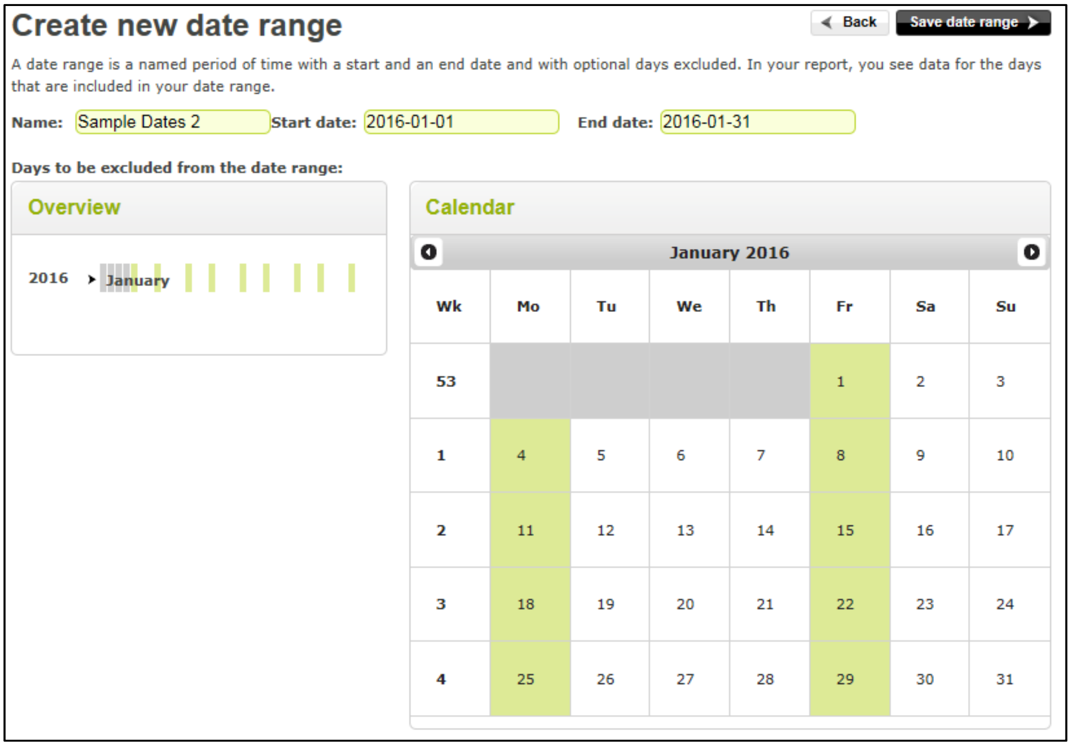


Figure B-4. Data Access Screen (Dates) for TomTom Custom Travel Time Tool

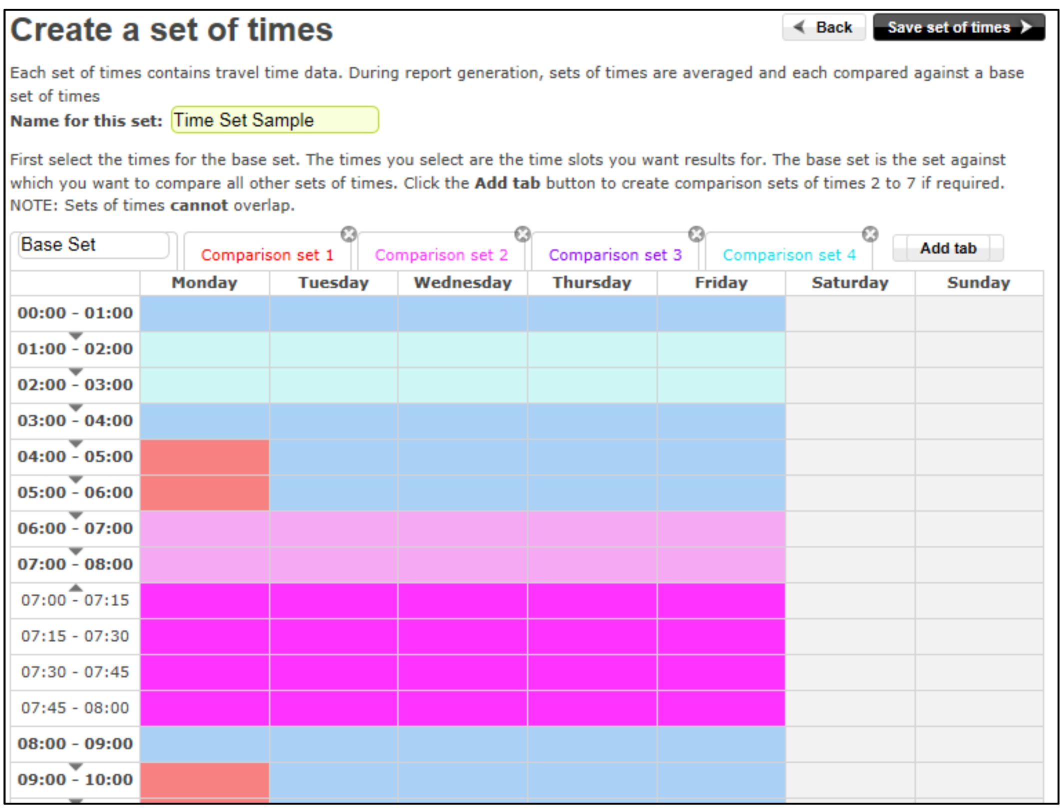


Figure B-5. Data Access Screen (Times) for TomTom Custom Travel Time Tool

B-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 B-6

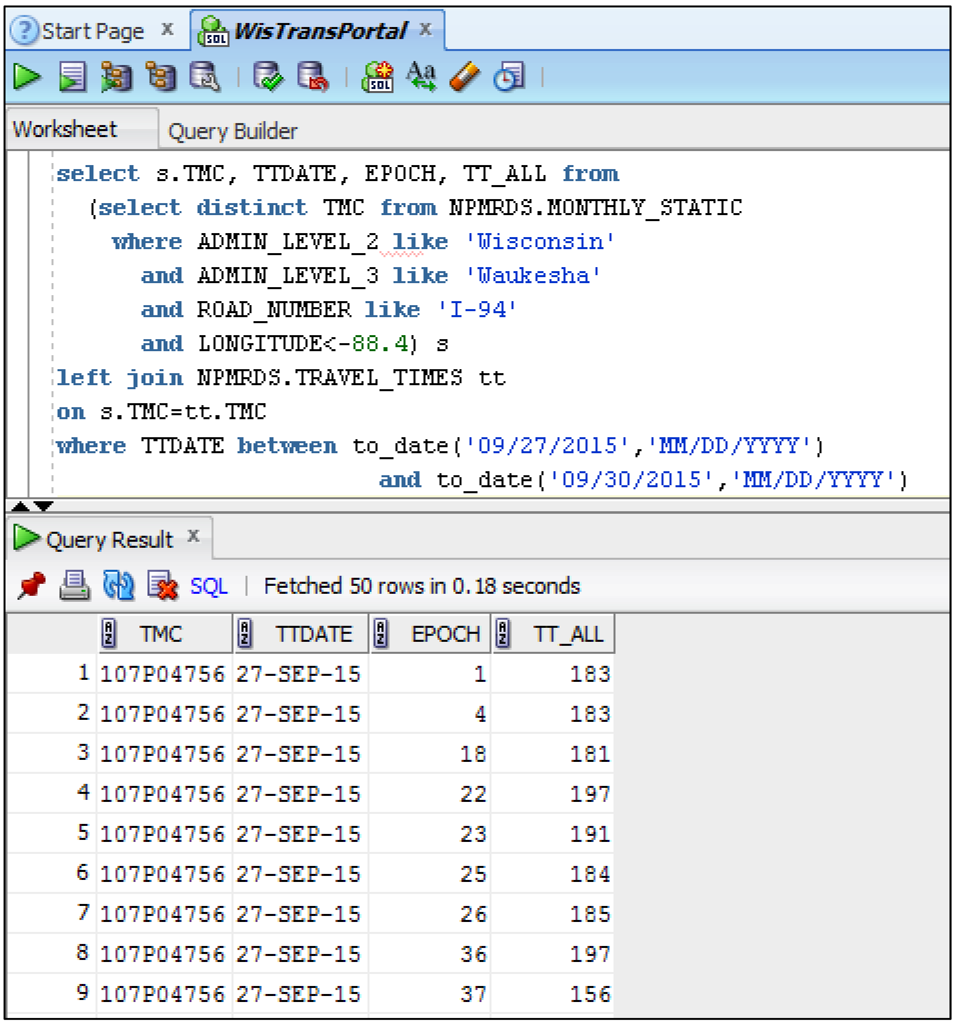


Figure B-6. Data Access Screen for NPMRDS (using Oracle SQL Developer)

B-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 B-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 B-7

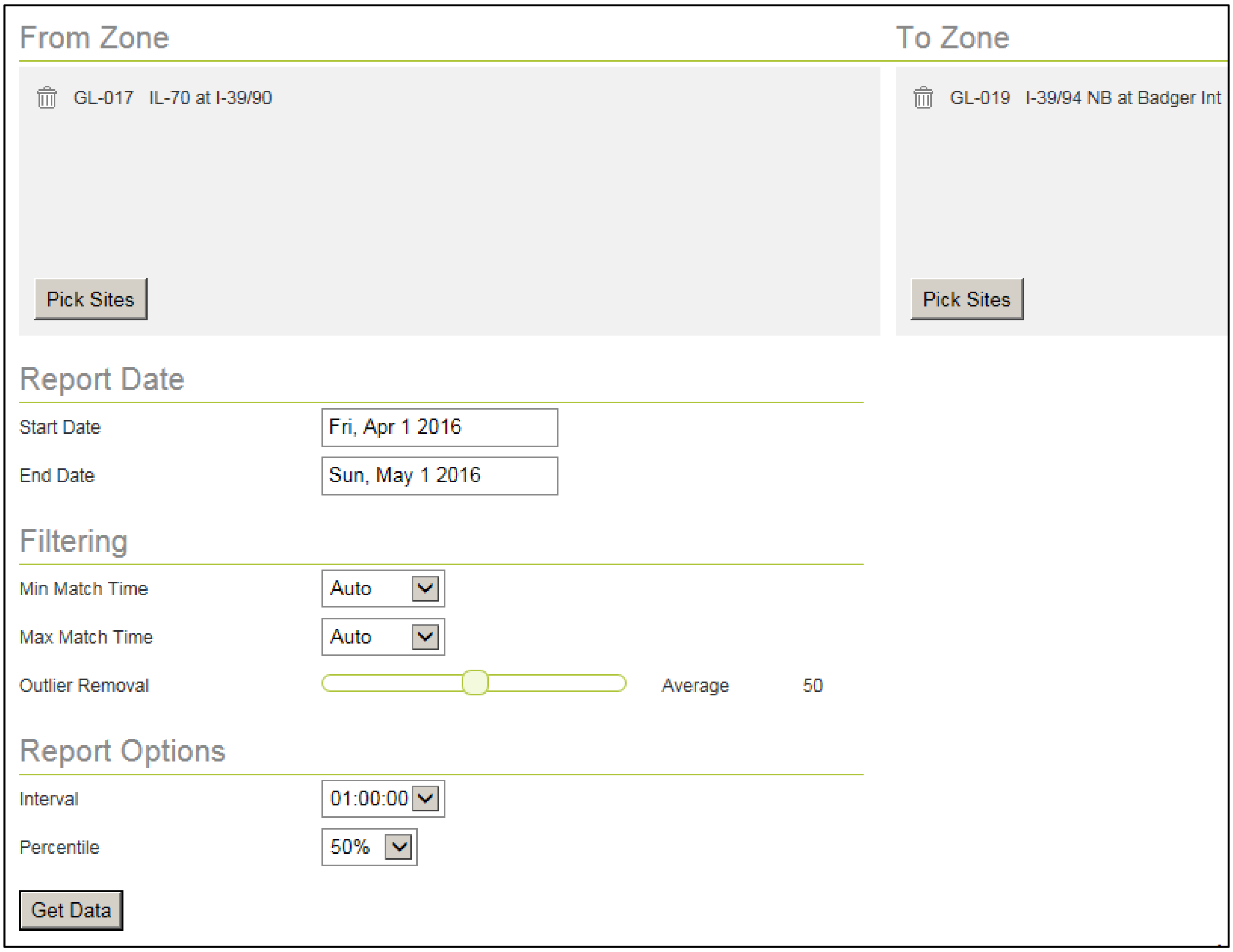


Figure B-7. Data Access Screen for Bluetooth Data (using Drakewell Online)

B-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 B-8

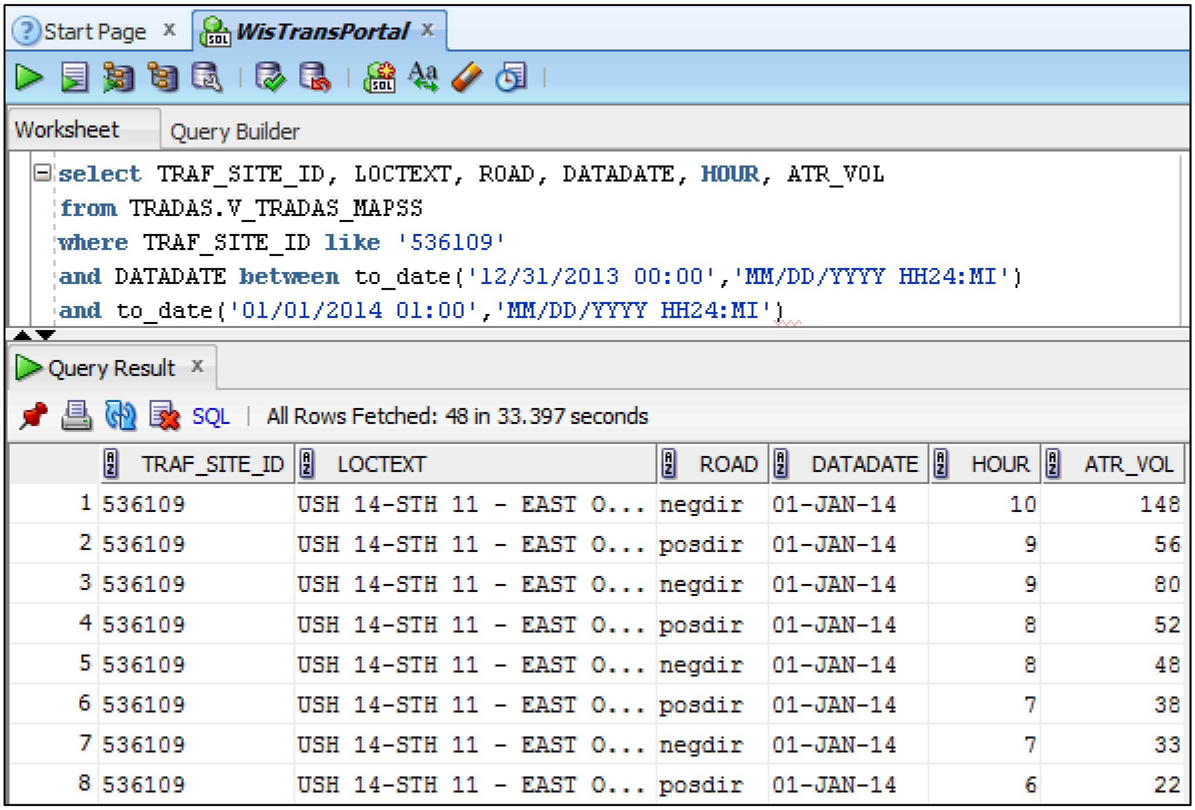


Figure B-8. Data Access Screen for ATR Data (using Oracle SQL Developer)

B-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 B-9 and B-10

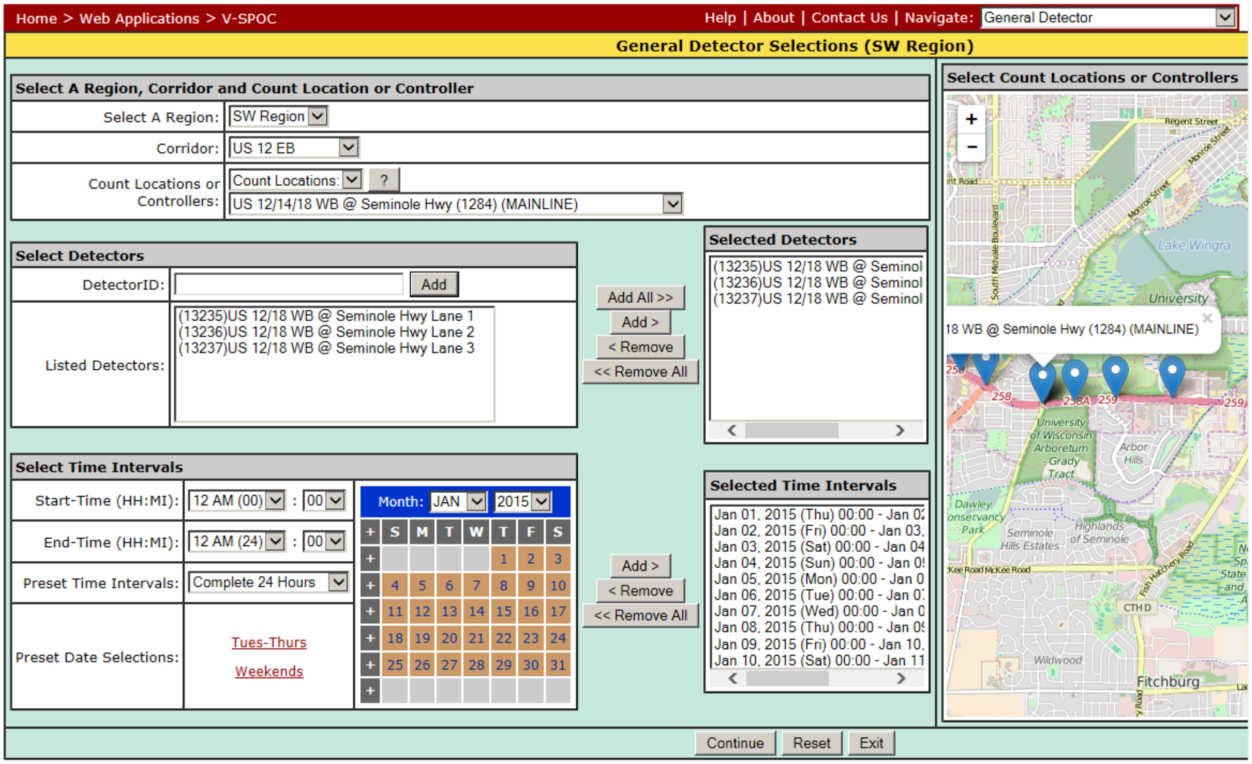


Figure B-9. Data Access Screen 1 for Microwave/Loop Data (using V-SPOC online)

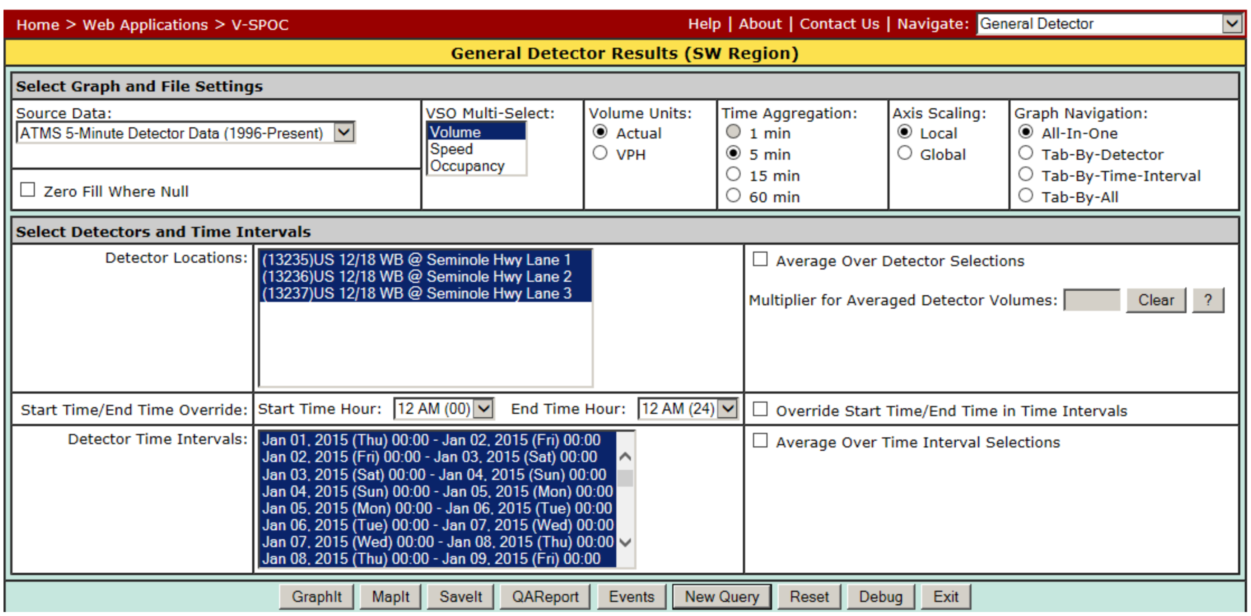


Figure B-10. Data Access Screen 2 for Microwave/Loop Data (using V-SPOC online)

B-4.2. Travel Time Computation

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

B-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.

B-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.

B-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.

B-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.

B-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.

B-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.

B-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

B-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.

B-5. Results

B-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.

B-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:

B-5.2.1. Literature Review (Appendix C 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 C 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.

B-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.

B-5.2.3. Final Report

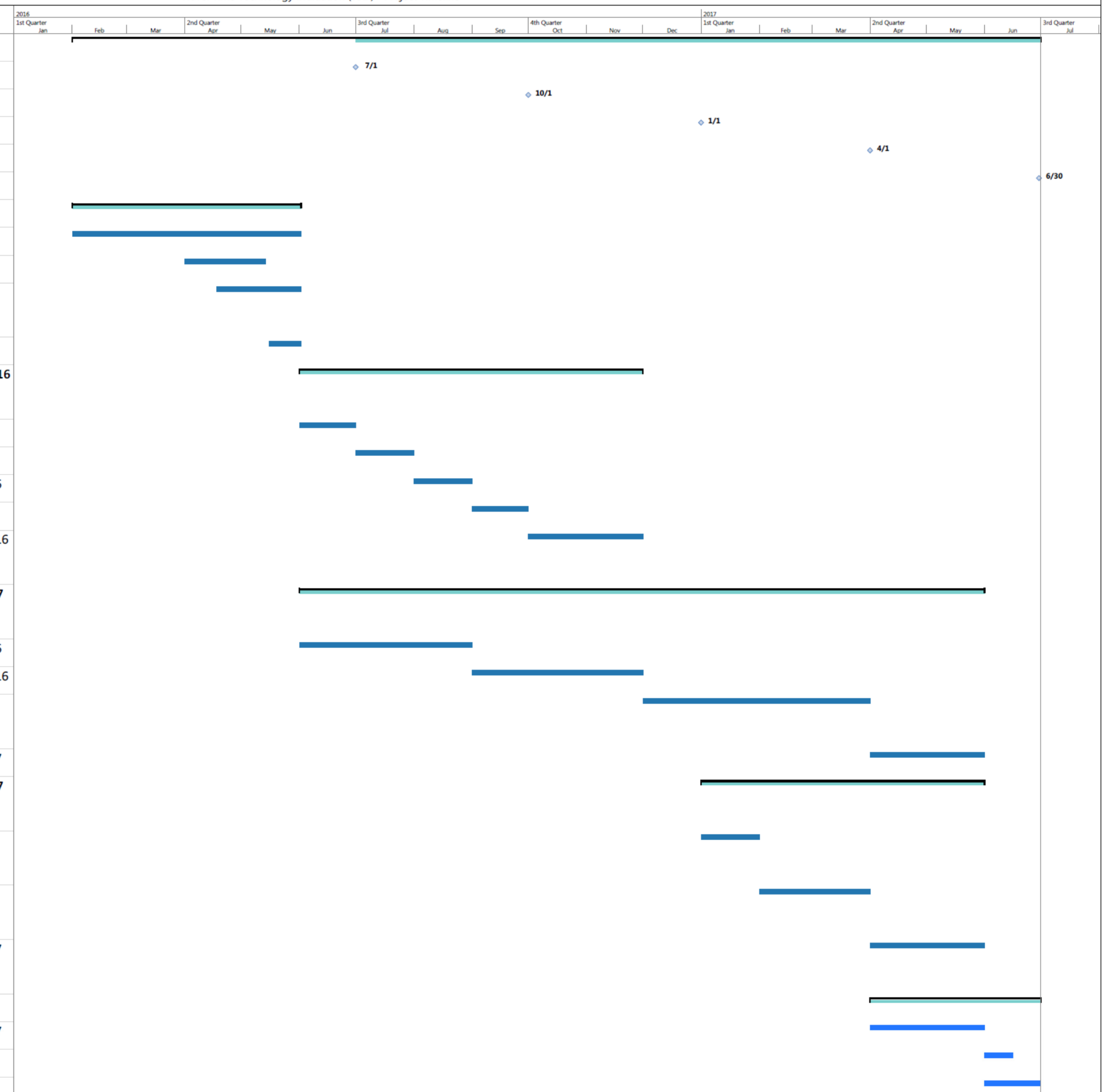
The final report will include all information regarding the process of comparing travel times and reliability. The cost effectiveness assessment will be included to summarize the results and offer recommendations for moving forward.

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 B-A. Project Management Timeline

Travel Time Technology Evaluation (T3E) - Project Timeline

ID	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

Page 1

Wisconsin DOT Travel Time Technology Evaluation (T3E)

TRAVEL TIME TECHNOLOGY EVALUATION

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

July 2016

Project Title: Travel Time Technology Evaluation (T3E)
Project ID Number: 0072-40-53
Master Contract Number: 0072-39-25
Work Order Number: 9.30
DTSD Big Ticket Number: BTO18
Object Code: 5501
Funding Appropriation: 365 – Highway system management and operations

Table of Contents

C-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.

C-2. Travel Time Estimation and Data Collection Technologies

C-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.

C-2.1.1. Loop Detectors[ii]

Half-Distance Approach

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:

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

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.

C-2.2. Probe Data Systems[iii]

C-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.

C-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.

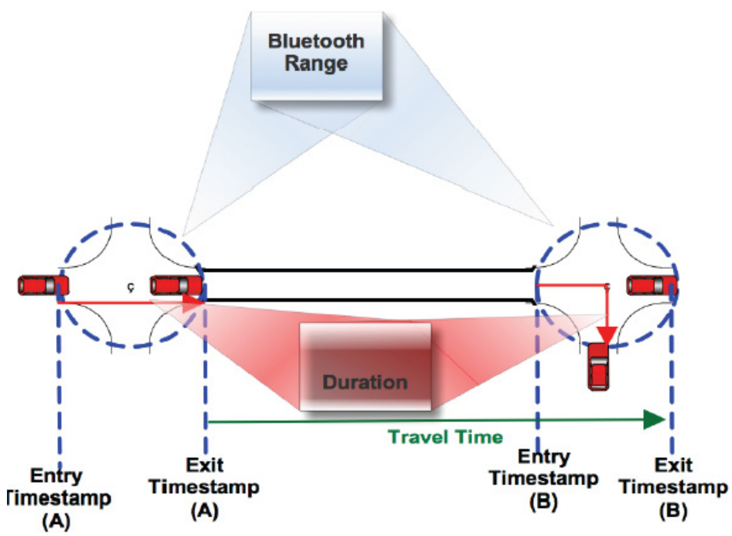
C-2.2.3. Bluetooth

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.



C-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.

C-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.

C-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.

C-3. Travel Time Estimation/Prediction Models

C-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 $U^c = 1$.

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

C-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.

C-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.

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

C-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]

C-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.

C-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.

C-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.

C-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]

C-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.

C-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 C-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 C-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%

C-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.

C-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.

C-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.

C-7. References

i Travel Time Data Quality Assessments 12-1-09. Pooled Fund Study. N.p., n.d. Web. 07 Jun. 2016 <http://www.pooledfund.org/Document/Download/1990>.

ii B, Coifman. Estimating Travel times and vehicle trajectories on Freeway using dual loop detectors. In Transportation Research Part A: Policy and Practice, Vol. 36, 2002, pp. 351-364.

iii L, Vanajahshi. Estimation and Prediction of Travel Time from Loop Detector Dat for Intelligent Transportation Systems Applications. A Dissertation submitted to the Office of Graduate Studies of Texas A & M University.

iv Vehicle Detection Quality Analysis. Wisconsin Department of Transportation. November 6, 2014

v Evans, M. K. (ed) (2003) Forecasting with A Single-Equation Regression Model, in Practical Business Forecasting, Blackwell Publishing Ltd, Oxford, UK. doi: 10.1002/9780470755624.ch5

vi A, Hadachi. Travel Time Estimation Using Sparsely Sampled Probe GPS Data in Urban Road Networks Context. Other [cs.OH]. INSA de Rouen, 2013. English. <NNT : 2013ISAM0003>. <tel-00800203>

vii Travel Time Quality Assurance and Quality Control, Wisconsin Department of Transportation / Bureau of Traffic Operations.

viii 2014 Real-time System Management Information Program Compliance Report. Federal Highway Administration California Division. Oct 20, 2014.

ix NCHRP 20-7 Guide to Benchmarking Operations Performance Measures Traffic Flow Performance Measures - Pilot Test Results.

x Athey Creek Consultants. Evaluation of Arterial Real-Time Traveler Information Commercial Probe Data Project. Minnesota Department of Transportation Project Report. July 31, 2012.

xi Y, Wang, et al. Error Assessment for Emerging Traffic Data Collection Devices. Pacific Northwest Transportation Consortium (PacTrans) University of Washington. Agreement T4118, Task 46 / DTRT07-G-00.

xii R, Gudishala., C, Wilmot., and A, Mokkapati. Travel Time Estimation Using Bluetooth. In National Center for Intermodal Transportation for Economic Competitiveness. LTRC Project, No. 13-2SS, SIO No. 30001396 Final Report 557.

xiii P, Rafferty., J Xu. Great Lakes Regional Transportation Operations Coalition Janesville Area Bluetooth Data Analysis. TOPS Lab. University of Wisconsin Madison, Project Report. March 2016.