Data-Driven Traffic Impact Assessment Tool for Work Zones

Final Report
March 2017

SWZDI
Smart Work Zone Deployment Initiative

Sponsored by
Smart Work Zone Deployment Initiative
Federal Highway Administration
(TPF-5(295) and InTrans Project 15-535)
Midwest Transportation Center
U.S. Department of Transportation
Office of the Assistant Secretary for
Research and Technology

MIDWEST TRANSPORTATION CENTER MTC

IOWA STATE UNIVERSITY
Institute for Transportation

About SWZDI

Iowa, Kansas, Missouri, and Nebraska created the Midwest States Smart Work Zone Deployment Initiative (SWZDI) in 1999 and Wisconsin joined in 2001. Through this pooled-fund study, researchers investigate better ways of controlling traffic through work zones. Their goal is to improve the safety and efficiency of traffic operations and highway work.

About MTC

The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC) sponsored by the U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology (USDOT/OST-R). The mission of the UTC program is to advance U.S. technology and expertise in the many disciplines comprising transportation through the mechanisms of education, research, and technology transfer at university-based centers of excellence. Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.

About InTrans

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16. Abstract

Traditionally, traffic impacts of work zones have been assessed using planning software such as Quick Zone, custom spreadsheets, and others. These software programs generate delay, queuing, and other mobility measures but are difficult to validate due to the lack of field data necessary for validation. One alternative approach for assessing the travel time impacts of a work zone is through data mining. Historical data of travel times observed during work zones and normal conditions can be used for work zone planning and scheduling.

This project developed a prototype tool using historical data for work zones in the St. Louis region in Missouri. Data from 782 work zones on I-70, I-270, and MO 141 that occurred between January 2014 and October 2015 were used. Several data sources were utilized in this project. These included electronic alerts of work zone information such as start and end times, location, lane closure information, and travel times. Spatially, the data included the work zone segment, two upstream segments, and all segments within a 2-mile radius of the work zone. Two delay measures were used for quantifying impact of work zones on freeway segments: travel time delay based on historical average travel times for the segment and travel time delay based on historical 15th percentile travel time values.

A model was developed to estimate travel times for planned work zones at sites that may not have sufficient historical work zone data. The Random Forests technique was used to develop the model. Separate models were developed for interstate and arterial work zones using historical travel times and speed profiles, work zone and upstream segment lengths, lane closure information, and work zone schedule. The predicted travel times were then utilized to compute delays. A prototype of the data-driven traffic assessment tool was developed. The predicted travel times for both interstate and arterial work zones were within 5% error.

For demonstration purposes, the scope of the prototype was limited to two interstate corridors and one arterial corridor. The tool uses four types of input information: work zone location, roadway direction, work zone duration, and work zone type and lane closure information. The tool then uses this information to mine the historical data to identify any work zones that occurred at the same location in the past. If a match is found, the historical data is utilized to generate the expected delay measures. If a match is not found, the Random Forests prediction model is used to generate the expected delay measures.

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DATA-DRIVEN TRAFFIC IMPACT ASSESSMENT TOOL FOR WORK ZONES

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This project was funded by the Midwest Transportation Center, the U.S. Department of Transportation (DOT) Office of the Assistant Secretary for Research and Technology, and the Smart Work Zone Deployment Initiative (SWZDI) and Federal Highway Administration (FHWA) Pooled Fund Study TPF-5(295), involving the following state departments of transportation:

- Iowa (lead state)
- Kansas
- Missouri
- Nebraska
- Wisconsin

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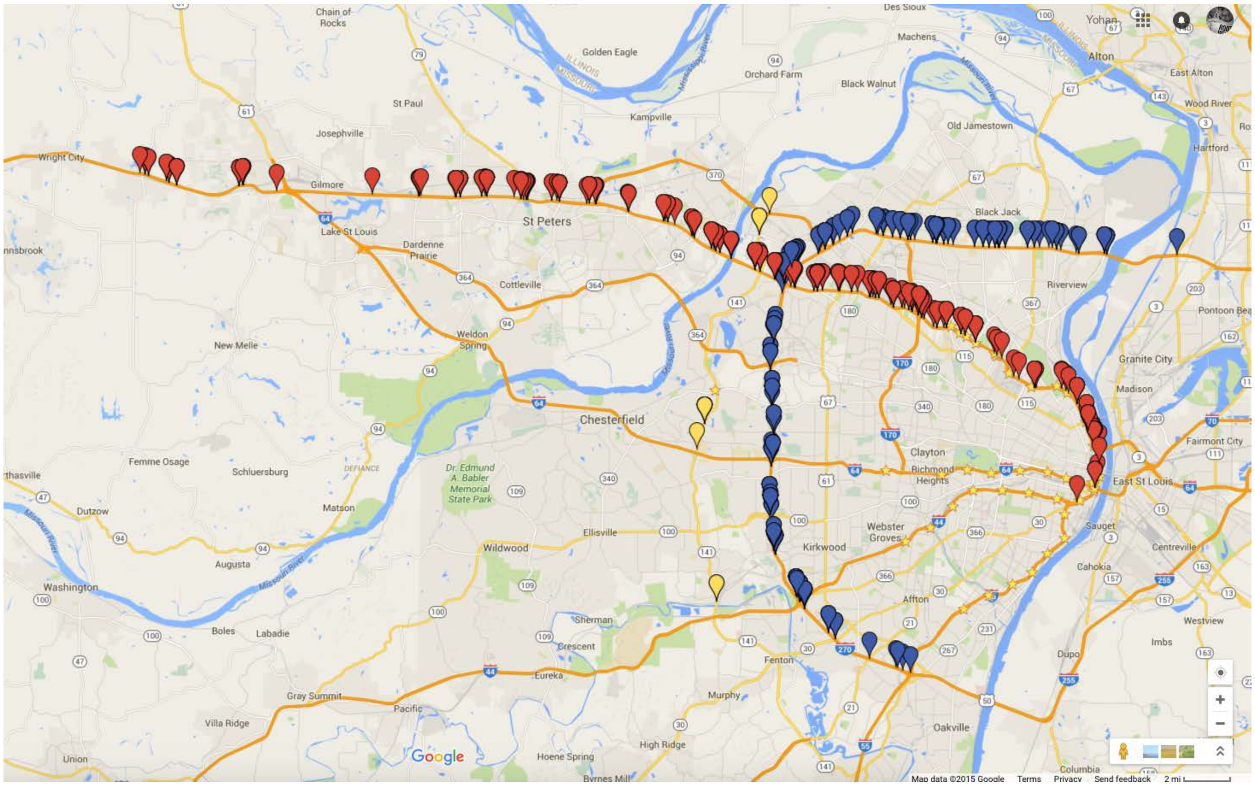
EXECUTIVE SUMMARY

Effective scheduling of roadwork requires accurate estimation of their traffic impacts. A variety of software tools have been developed to estimate work zone mobility impacts, including Quick Zone, custom spreadsheets, and QUEWZ. Microscopic simulation tools such as VISSIM and CORSIM have also been utilized.

These software tools generate mobility measures such as delay and queuing and can be used for scheduling work zones to minimize their impacts. Calibration and validation of these tools has been a challenge due to the lack of necessary field data. The underlying assumptions and the parameters of the queuing models do not allow for an accurate calibration for all performance measures such as queue length, delay, etc. In contrast to the previous approaches that used deterministic queuing methods (e.g., Quick Zone) to predict the traffic impacts of a planned work zone, this study developed a data-driven method that uses historical data to derive the performance measures. The proposed method helps to quantify the effect of a work zone by comparing performance measures such as speeds and travel times (or delay) with and without the presence of the work zone.

The proposed method was applied for a sample of work zones in the St. Louis region in Missouri. Gateway Guide, the Missouri Department of Transportation's (MoDOT's) traffic management center (TMC) in St. Louis, generates electronic alerts for various events, including work zones. These alerts provide real-time updates of the schedule, duration, and characteristics of work zones. The alert has several attributes of a work zone: current status (new, update, or cleared), type of work, route name, work zone location, and lane closure information. A procedure was then developed to automate the extraction of relevant work zone information from electronic alerts. The procedure involved first converting the alert into a text file and then splitting the message into the various work zone attributes described earlier. The location extracted from the alert was mapped onto Google Maps to identify the exact latitude and longitude. There were 801 work zone-related alerts (more than one alert for each work zone) from January 2014 to September 2015: 387 for I-70, 398 for I-270, and 16 for MO 141. Figure ES1 maps all the locations extracted from the electronic alerts.



Map data ©2015 Google

Figure ES1. Work zone locations obtained from electronic alerts

The travel time data used in this project were obtained from the Regional Integrated Transportation Information System (RITIS). Queries were executed to obtain data for the work zone and two immediately upstream segments. Queried data from the RITIS database consist of several types: travel time and speed for segments and information on TMC codes identifying the segments. The impact of a specific freeway work zone in its vicinity was assessed using delay measures. Travel time delay was computed in several ways: using historical average travel time, using historical maximum travel time, and using historical 15th percentile travel time. The historical values include data for the same day of the week and time of day from previous three weeks.

In addition to the work zone and upstream segments, all adjacent road segments within a certain radius of the work zone are also analyzed to identify if the work zone had any impact on their travel times. Radius values of 1 mile and 2 miles from the work zone segment's beginning location were examined. A prediction model was developed to predict travel times for planned work zones. The model development framework is shown in Figure ES2.

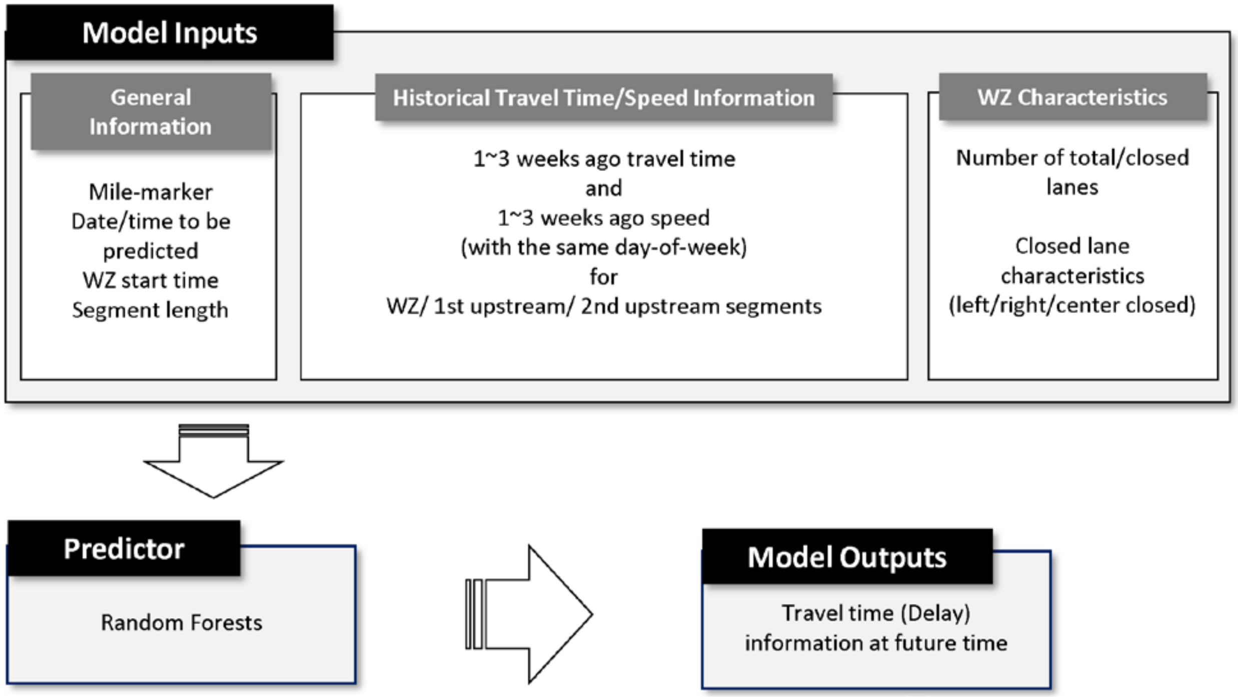
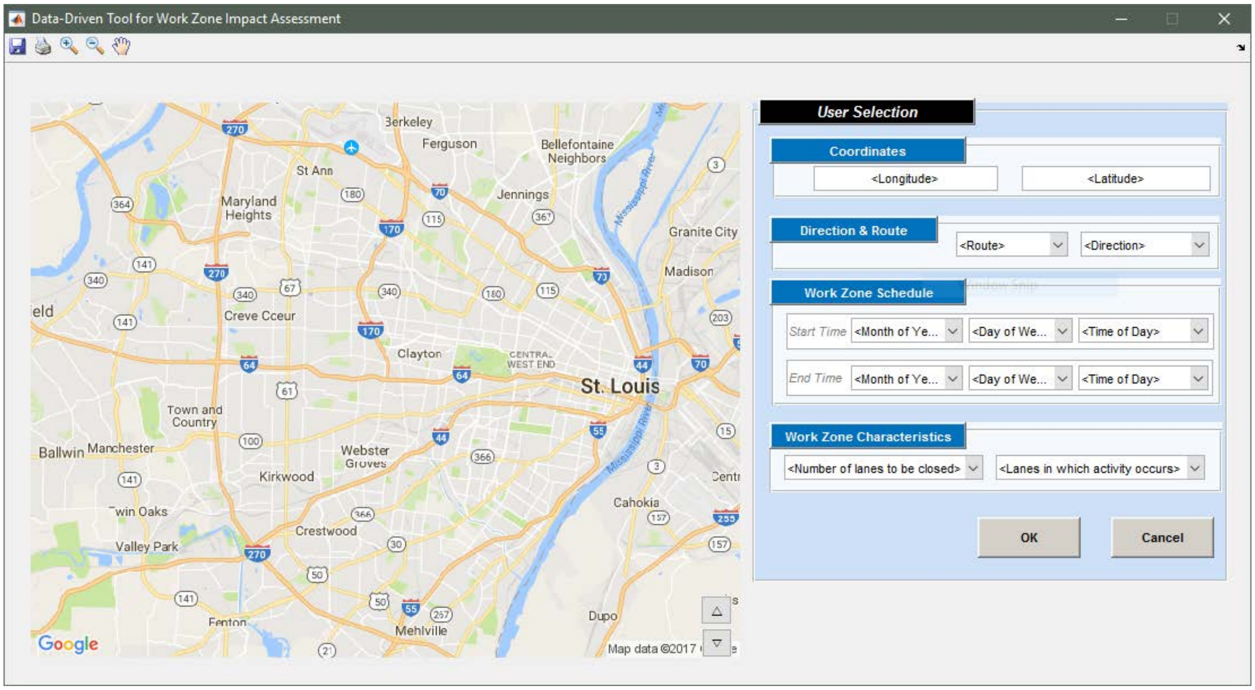


Figure ES2. Framework of the travel time prediction model

Data describing the work zone is inputted and used in conjunction with historical data. The Random Forests model then produces estimates of the future travel time delay (based on predicted travel times). A total of 27 variables are used in model development.

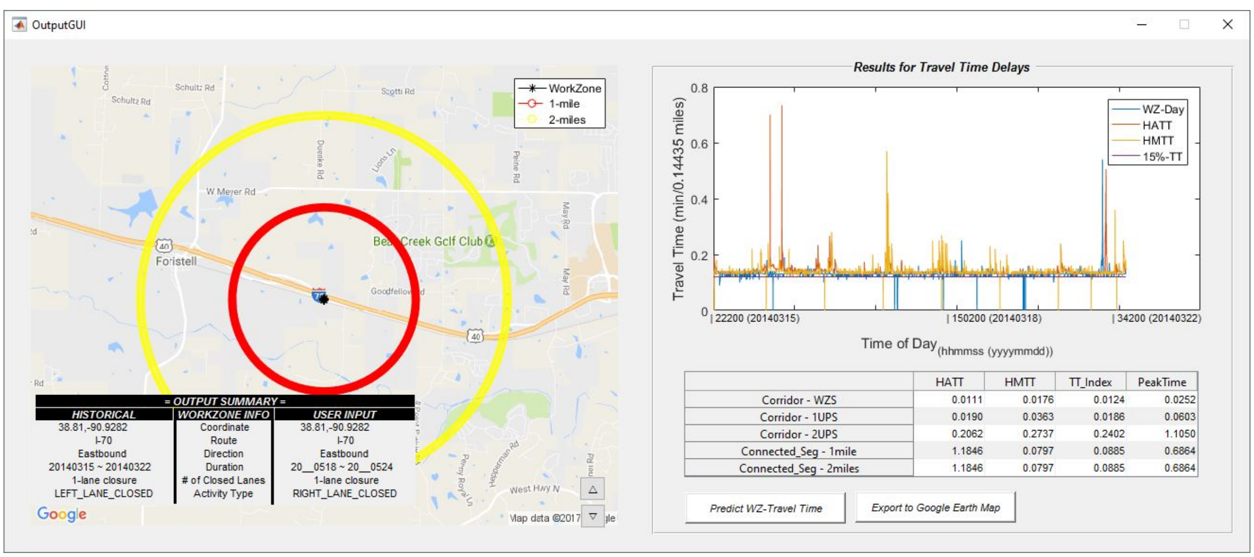
A prototype of the proposed data-driven traffic assessment tool was developed using the sample work zone data from the St. Louis region. Four types of input information are entered as input by a user: work zone coordinates, roadway direction, work zone duration, and lane closure information. The tool uses this information to mine the historical data to identify any work zones that occurred at the same location in the past. If a match is found, the data is utilized to generate the expected delay measures. If a match is not found, the travel time prediction model is used to generate the expected delay measures. The predicted travel times for both interstate and arterial work zones were within 5% error. A screenshot of the prototype's input window is shown in Figure ES3.



Map data ©2017 Google

Figure ES3. Screenshot for DDT_WZ software

A screenshot of the output window is shown in Figure ES4.



Map data ©2017 Google

Figure ES4. Screenshot for output graphical user interface

The left side of the output window shows the work zone location on a map and the right side plots the travel time measures for a work zone segment. The table below the plot reports the delays (in minutes) for the work zone segment, upstream segments, and adjacent segments impacted by the work zone. On the left side of the output window, the red circle shows the 1-mile boundary around work zone and the yellow circle shows the 2-mile boundary. A summary of the input data entered by the user is printed at the bottom left of the screen.

The prototype can be enhanced in the future by including additional road segments from Smart Work Zone Deployment Initiative (SWZDI) pooled fund states. Other roadway types such as two-lane roads and minor arterials could also be added to the tool to help quantify the traffic impacts from work zones.

INTRODUCTION

State departments of transportation (DOTs) use several approaches to enhance safety and mobility in work zones. These approaches include better scheduling of work activity, improved traffic management plans, and use of innovative technology (e.g., queue warnings). Accurate assessment of traffic impacts are critical to work zone scheduling.

Research on the development of traffic impact assessment tools for work zones dates back to the late 1990s. State of the practice studies documenting these research efforts can be found in Edara (2006, 2009), Edara and Cottrell (2007), Edara et al. (2013), and Savolainen et al. (2015). Existing tools can be broadly categorized into four areas: impact assessment guidelines, traffic simulation applications, parametric approaches, and non-parametric approaches. Table 1 categorizes existing studies into these four areas.

Table 1. Studies pertaining to work zone traffic impact assessment

Emphasis area	Literature
Work zone impact assessment guidelines	Sankar et al. 2006, Ullman et al. 2011, Bourne et al. 2011, Mallela and Sadasivam 2011
Traffic simulation applications	Chien et al. 2002, Meng and Weng 2010, Astarita et al. 2014, Edara 2006, Edara et al. 2013
Parametric approaches	Jiang 2001, Schroeder and Rouphail 2010, Edara 2009, Edara et al. 2013, Dixon et al. 1996, Savolainen et al. 2015
Non-parametric approaches	Ghosh-Dastidar and Adeli 2006, Weng and Meng 2012

A variety of software tools have been developed to estimate work zone mobility impacts, including Quick Zone, custom spreadsheets, and QUEWZ. Microscopic simulation tools such as VISSIM and CORSIM have also been utilized to quantify traffic impacts of work zones. These software tools generate mobility measures such as delay and queuing and can be used for scheduling work zones to minimize their impacts. However, calibration of these software tools and validation of their results has been a challenge, due to the lack of necessary field data (Edara et al. 2013). The underlying assumptions and parameters of the queuing models do not allow for an accurate calibration for all performance measures, such as queue length or delay.

In contrast to the previous approaches that used deterministic queuing methods (e.g., Quick Zone) to predict the traffic impacts of a planned work zone, this study developed a data-driven method that uses historical data to derive the performance measures. A statistical data mining approach uses historical data from work zones in a region to develop the relationships between the performance measures and the explanatory variables. The data-mining method helps to quantify the effect of work zones by comparing performance measures such as speeds, travel times (or delay), and queue length, with and without the presence of the work zone.

This data-driven approach relies on travel-time data continuously collected over the study segments. Travel time data (e.g., probe-based) has recently become available over large coverage areas from third party sources such as the Regional Integrated Transportation Information System (RITIS), INRIX, and HERE. The quality of data obtained from these sources has been examined by Edwards and Fontaine (2012) for work zone applications and by Rakha et al. (2013) and Chen et al. (2015) for generic transportation applications.

A prototype of the data-driven approach was developed using historical data of work zones in the St. Louis region in Missouri. The prototype tool computes three travel time measures: 15th percentile travel time, historical average travel time, and historical maximum travel time. The historical values include data for the same day of the week and time of day from the previous three weeks. These measures are used to estimate work zone delays for both the work zone segment and all adjacent roadway segments within a radius of 1.0 mile and 2.0 miles around the work zone.

DATA ACQUISITION AND ANALYSIS

1. Work Zone Information from Traffic Management Center Electronic Alerts

The Missouri Department of Transportation (MoDOT) traffic management center (TMC) in the St. Louis region, Gateway Guide, generates electronic alerts for various events, including work zones. These alerts provide real-time updates of the schedule, duration, and characteristics of work zones. A sample alert is shown in Figure 1.

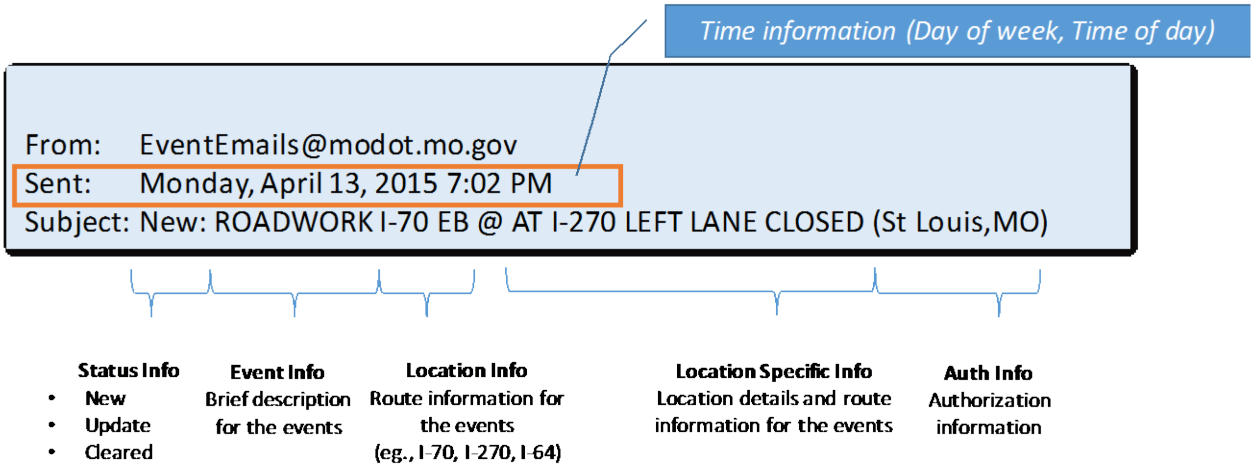
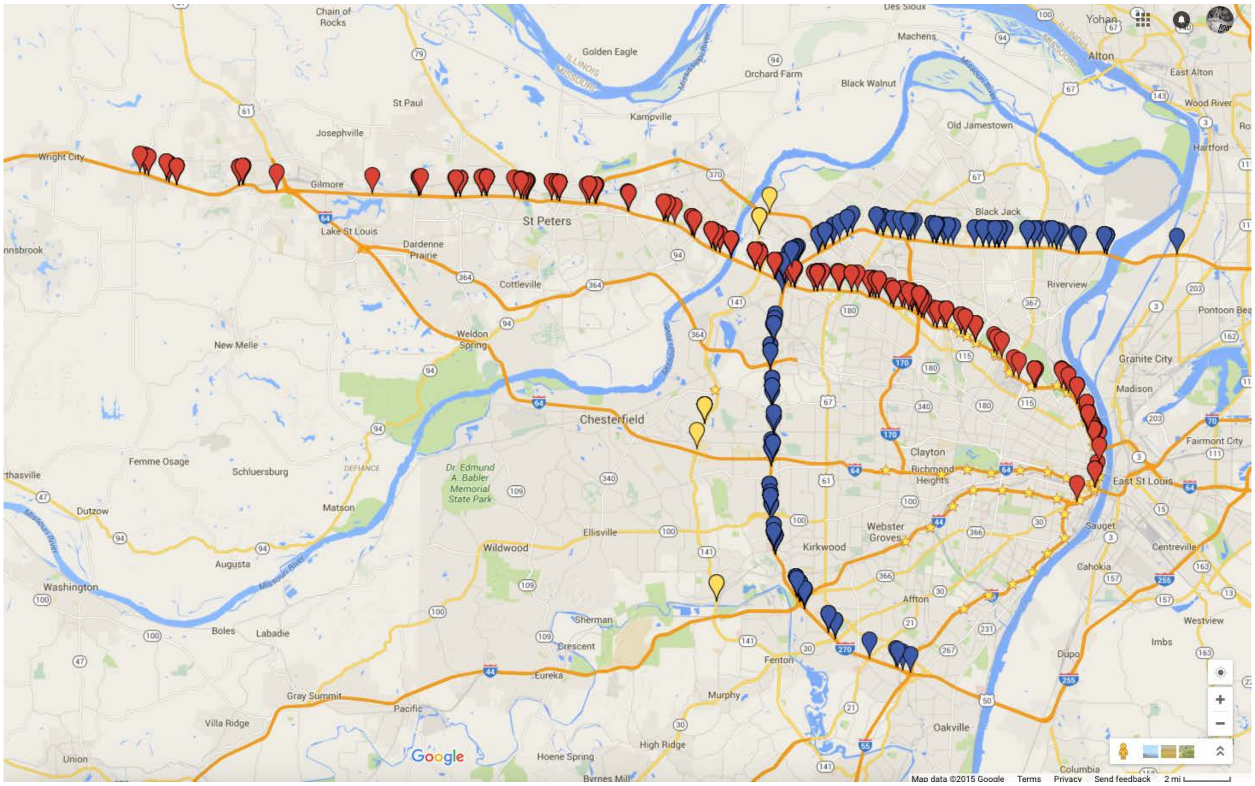


Figure 1. Example of MoDOT's electronic alert

The alert has several attributes of a work zone: current status (new, update, or cleared), type of work, route, work zone location, and lane closure information. The TMC sends the alerts to the relevant traffic management partners and also shares the information found in the alerts with the public via social media, such as Facebook and Twitter.

A procedure was developed to automate the extraction of relevant work zone information from electronic alerts. The procedure involved first converting the alert into a text file and then splitting the message into the various work zone attributes described. The location extracted from the alert was mapped onto Google Maps to identify the exact latitude and longitude.

There were 801 work zone-related electronic alerts (more than one alert for each work zone) from January 2014 through September 2015: 387 for I-70, 398 for I-270, and 16 for MO 141 (see Figure 2).



Map data ©2015 Google

Figure 2. Work zone locations obtained from electronic alerts

The annual average daily traffic (AADT) statistics for these routes are presented in Table 2.

Table 2. AADT statistics for the study routes in 2015

Route	Average AADT		Standard deviation of AADT		Maximum AADT		Minimum AADT	
	Traffic	Truck	Traffic	Truck	Traffic	Truck	Traffic	Truck
I-70	108,497	22,470	41,037	26,016	166,229	80,219	28,964	3,133
I-270	140,521	22,419	39,234	4,972	193,574	30,871	53,495	17,917
MO 141	42,698	2,459	14,902	999	70,125	4,036	17,461	1,109

2. Work Zone Duration, Length, and Lane Closure

Work zones were classified based on their duration. The classification shown in Figure 3 shows that the sample was dominated by short-term work zones with durations less than one day and long-term work zones with durations of more than three months.

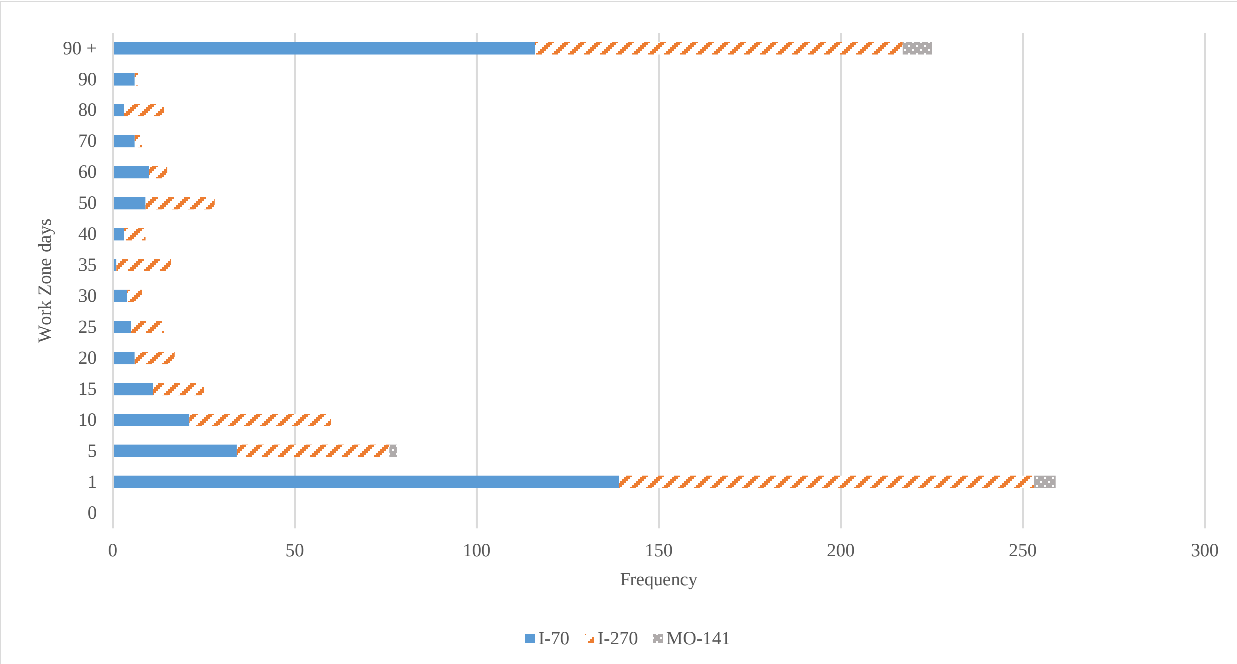


Figure 3. Distribution of work zone durations

The work zones were also classified by the lane closure information included in the electronic alerts, as shown in Figures 4 and 5. There were 11 types of lane closure information that were included in the alerts for the freeway work zones on I-270 and I-70. Figure 4 shows the proportion of work zones by number of closed lanes and which lanes were closed.

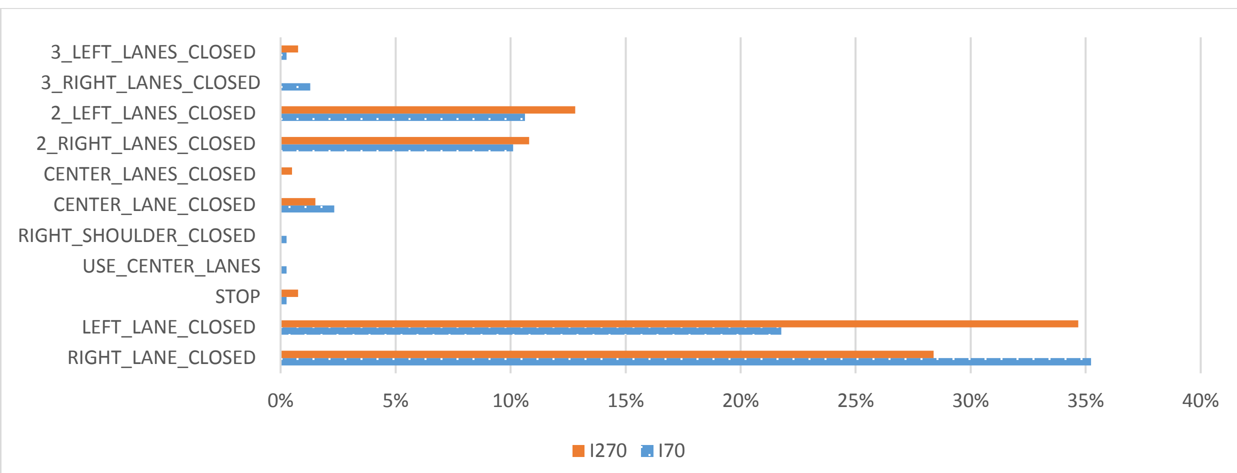


Figure 4. Distribution of I-70 and I-270 work zones by lane closures

The alerts for work zones on MO 141 arterial routes included lane closure information of three types as shown in Figure 5. In Figure 5, All duration means work zones with both less than one day and more than one day included.

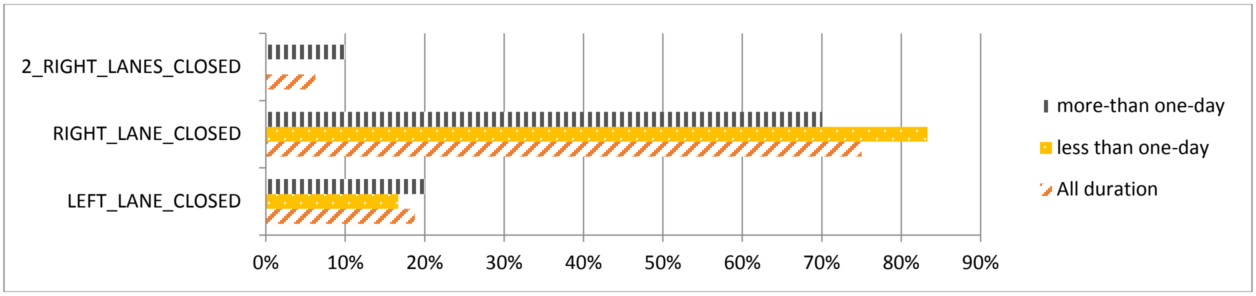


Figure 5. Distribution of MO 141 work zones by lane closures

Table 3 and Figure 6 show general statistics for less than one day and more than one day duration work zones.

Table 3. General statistics for work zone lengths

Length (miles)	Less than One Day			More than One Day		
	I-70	**I-270**	**MO 141**	**I-70**	**I-270**	**MO 141**
Mean	1.704	0.729	0.469	2.606	1.972	0.480
STDEV	4.231	0.381	0.389	5.240	1.812	0.313
Median	0.750	0.825	0.361	0.741	1.225	0.361

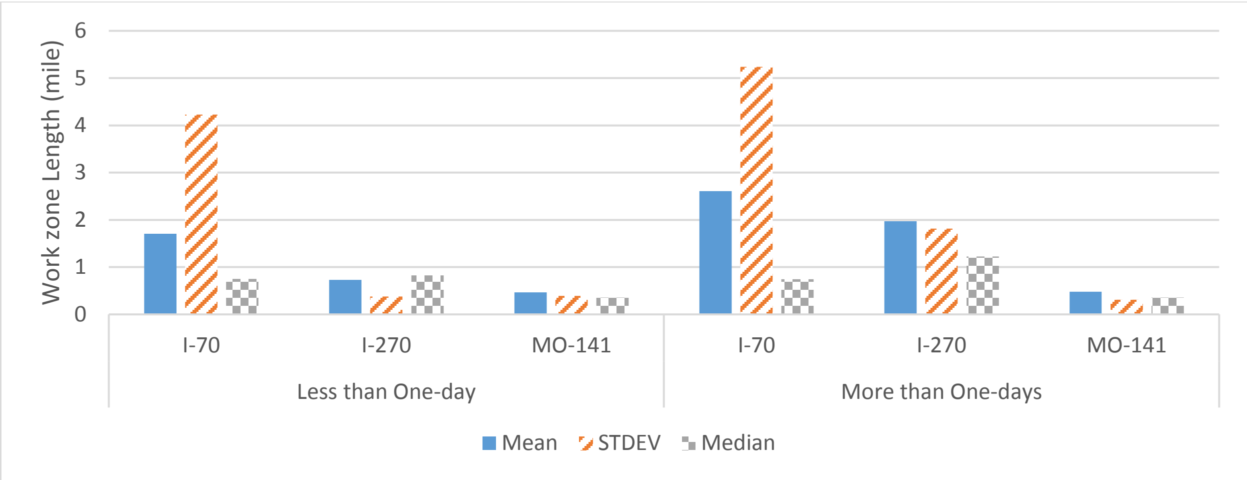


Figure 6. Comparison of work zone lengths

3. Identifying Segments Affected by the Work Zone

The electronic alerts contained information on the work zone locations. This information was used to determine three travel time segments: 1) the work zone segment, 2) the segment immediately upstream of work zone segment (1st upstream), and 3) the segment immediately upstream of the 1st upstream segment (2nd upstream). The identified upstream and work zone travel time segments for all work zones on I-70 and I-270 are shown in Figure 7.

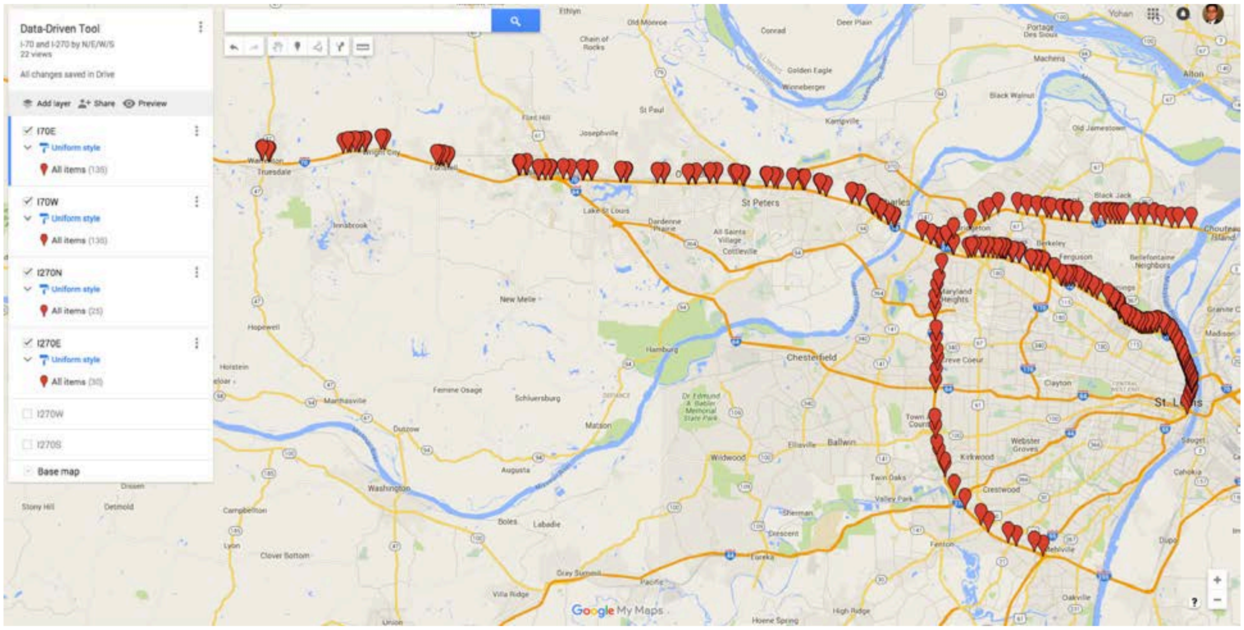


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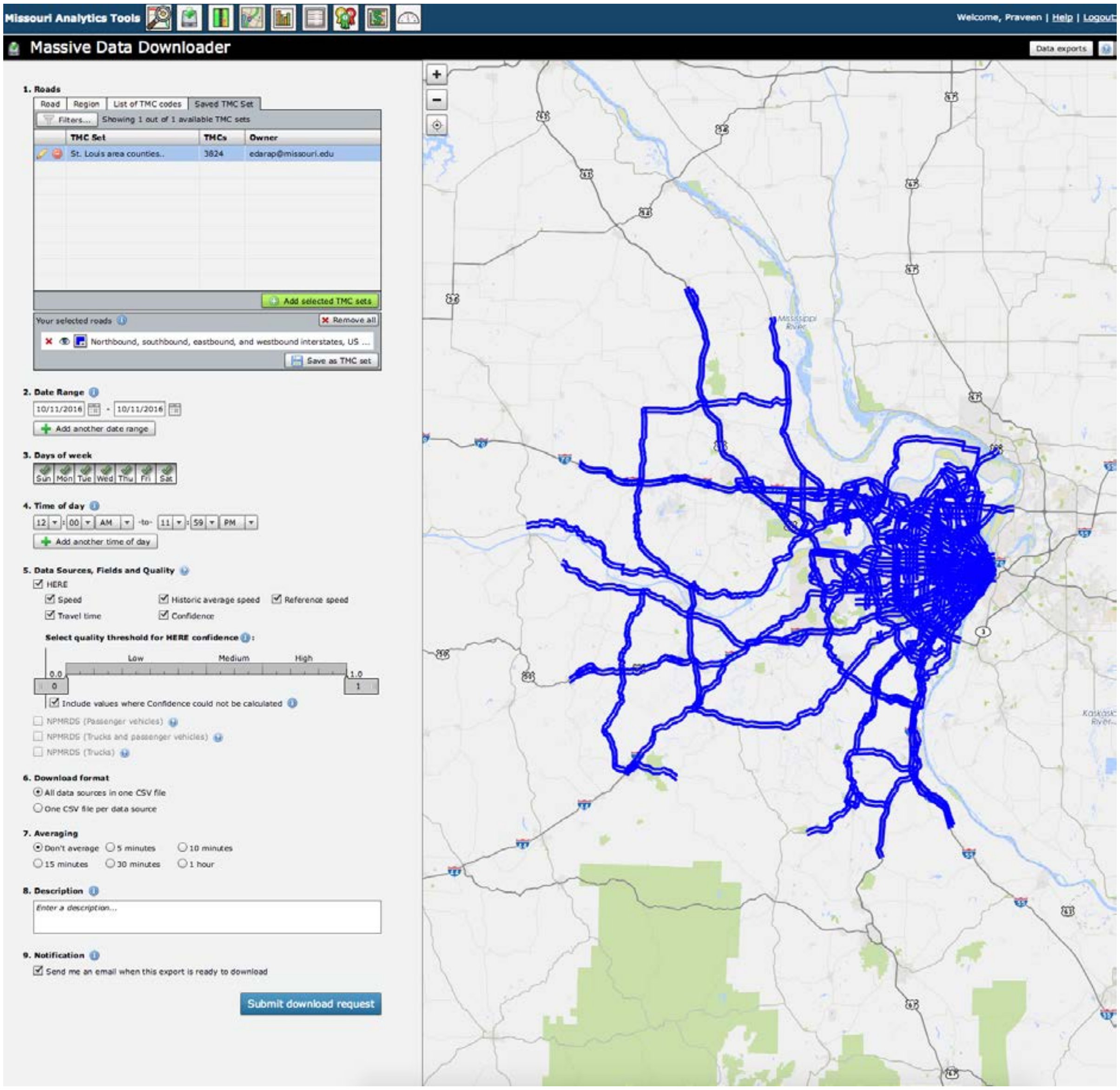
Figure 7. Work zone and upstream travel time segments

4. Travel Time Data

The travel time data used in this project was obtained from the RITIS. MoDOT has an agreement for the RITIS to receive travel time data for roadways across the state. The proposed methodology and the tool are independent of the source of the travel time data. States that obtain travel time data from other vendors such as INRIX can still utilize the proposed method to develop a work zone impact assessment tool.

A screenshot of the data query window of the RITIS is shown in Figure 8 with the right side showing a map of the coverage of freeways in the St. Louis area and the left side showing query criteria such as date, time, and duration, and data format. Queries were executed to obtain data for all segments identified in the previous section (previously shown in Figure 7).



RITIS website

Figure 8. RITIS data query interface and detector deployment in St. Louis area

Queried data from the RITIS database consists of several types: travel time and speed for segments and information on TMC codes identifying the segments. Figure 9 provides sample screenshots of the two types of output.

tmc_code	measurement_tstamp	speed	average_speed	reference_speed	travel_time_minutes	confidence
119-12871	01/01/2015 12:00:18 AM	31.69	30.97	25	0.69	0.7
119N13546	01/01/2015 12:00:18 AM	37.9	34.77	33	0.08	0.7
119P13325	01/01/2015 12:00:18 AM	24.86	24.85	45	0.28	0.7
119N04183	01/01/2015 12:00:18 AM	56.15	48.62	52	0.8	0.85
119-12859	01/01/2015 12:00:18 AM	39.15	43.25	36	0.52	0.7
119P13630	01/01/2015 12:00:18 AM	23.61	28.23	26	0.15	0.7
119N13621	01/01/2015 12:00:18 AM	34.18	34.18	27	0.08	0.7
119-13434	01/01/2015 12:00:18 AM	20.51	25.54	19	0.59	0.7

tmc	road	direction	intersection	state	county	zip	start latitude	start longitude	end latitude	end longitude	miles	road order
119+13650	Bellefontaine Rd	NORTHBOUND	I-270/Dunn Rd	MO	ST LOUIS	63137	38.74948	-90.22402	38.76942	-90.22088	1.38731	6
119P13650	Bellefontaine Rd	NORTHBOUND	I-270/Dunn Rd	MO	ST LOUIS	63138	38.76942	-90.22088	38.77023	-90.22074	0.056411	7
119-13650	Bellefontaine Rd	SOUTHBOUND	I-270/Dunn Rd	MO	ST LOUIS	63138	38.79406	-90.21385	38.77023	-90.22074	1.68779	2
119N13650	Bellefontaine Rd	SOUTHBOUND	I-270/Dunn Rd	MO	ST LOUIS	63138	38.77023	-90.22074	38.76942	-90.22088	0.056411	3
119+13508	Big Bend Rd	EASTBOUND	I-270	MO	ST LOUIS	63122	38.5672	-90.47614	38.56711	-90.44095	2.06902	6
119P13508	Big Bend Rd	EASTBOUND	I-270	MO	ST LOUIS	63122	38.56711	-90.44095	38.56735	-90.43921	0.095707	7
119-13508	Big Bend Rd	WESTBOUND	I-270	MO	ST LOUIS	63122	38.56696	-90.43079	38.56735	-90.43921	0.45771	8
119N13508	Big Bend Rd	WESTBOUND	I-270	MO	ST LOUIS	63122	38.56735	-90.43921	38.56711	-90.44095	0.095707	9
119+13618	Dorsett Rd	EASTBOUND	I-270	MO	ST LOUIS	63043	38.71454	-90.45399	38.71454	-90.44833	0.306022	3
119P13618	Dorsett Rd	EASTBOUND	I-270	MO	ST LOUIS	63043	38.71454	-90.44626	38.71454	-90.44833	0.113363	4

Figure 9. Mobility measures (top) and TMC codes (bottom)

The travel time and speed information (top part of Figure 9) consists of seven fields: TMC code, time stamp, speed, average speed, reference speed, travel time, and confidence level. The bottom part of Figure 9 shows descriptive information of unique TMC codes that identify RITIS segments; this information includes road, direction, intersection, state, county, zip, start and end latitude/longitude, segment miles, and road order.

The time stamp includes information about time, i.e., date (month, day, and year) and time of day (hour, minute, and second). Three types of speeds (all in miles per hour) are reported for each segment in RITIS: prevailing speed, historical average speed, and reference speed (free flow speed). These speed measures, travel time, and confidence levels are defined in Figure 10.

Data Types

Vendor-Provided Data

Speed — The current estimated harmonic mean speed for the roadway segment in miles per hour.

Travel Time — Time it will take to drive along the roadway segment (Distance Traveled / Speed).

Reference Speed — The calculated "free flow" mean speed for the roadway segment in miles per hour. This attribute is calculated based upon the 85th-percentile point of the observed speeds on that segment for all time periods, which establishes a reliable proxy for the speed of traffic at free-flow for that segment.

Historic Average Speed — The historical average speed for the roadway segment for that hour of the day and day of the week in miles per hour.

Comparative Speed — Measured speed as a percentage of the historic average speed for this time of day and day of week.

Congestion — Measured speed as a percentage of the free flow speed.

Historic Average Congestion — Historic average speed as a percentage of the free flow speed for this time of day and day of week.

Confidence — This is a simple confidence factor.

- Between 0.7 and 1.0 (including 1.0) - high confidence, based on real-time data for that specific segment
- Between 0.5 and 0.7 (including 0.7) - medium confidence, based on a combination of historic and real-time data
- Between 0.0 and 0.5 (including 0.5) - lower confidence, based primarily on road reference speeds

RITIS data help

Figure 10. Data description of RITIS database

5. Work Zone Travel Time Delay Measures

The impact of a specific freeway work zone and its vicinity is assessed using delay measures. Three segments on freeways were analyzed for impact: work zone segment, 1st upstream segment, and 2nd upstream segment. While these segments capture the greatest impact of the work zone, other road segments adjacent to the freeway may also be impacted by the work zone. To this end, all adjacent road segments within a certain radius of the work zone were also analyzed to identify if the work zone had any impact on their travel times.

Freeway Segments

Two delay measures were adopted for quantifying the impact of work zones on freeway segments: travel time (TT) delay based on historical average travel times for the segment and TT delay based on historical 15th percentile travel time values.

Travel Time Delay Using Historical Average Travel Time

Travel time delay was calculated using the following equation:

$$\left[\sum_{t=1}^{T}\left(\frac{\mathrm{WZ\,TT}_t - \mathrm{HATT}_t}{s}\right)\right]/n_T \qquad \textbf{(1)}$$

where, S is segment length, WZ TT_t is the travel time when the work zone was present, $HATT_t$ is the historical average travel time computed by averaging the travel times in the past three weeks for the same segment, same time of day, and same day of the week, and n_γ is the number of observations comprised within the work zone duration.

Travel Time Delay Using 15th Percentile Travel Time

The second delay measure uses a different baseline travel time to compute delay. The previous delay measure uses historical three-week average travel times as the baseline while this delay measure uses the 15th percentile historical travel time as the baseline. The 15th percentile travel time was exceeded 85 percent of the time, and thus serves as an estimate of the travel time under free flow conditions.

The TT delay using 15th percentile travel time was computed as follows:

$$\left[\sum_{t=1}^{T}\left(\frac{\text{WZ TT}_t - 15^{th}\text{ percentile TT}}{S}\right)\right]/n_T \quad \textbf{(2)}$$

Adjacent Road Segments within a Certain Radius of Work Zone

The travel times on all adjacent road segments within a specified radius of the work zone segment were also examined to detect if the work zone impacted those segments. Three delay measures were computed: TT delay using historical average travel time (Equation 1 previously defined), TT delay using historical maximum travel time (obtained by replacing historical average with historical maximum travel time in Equation 1, and denoted by HMTT), and TT delay using historical 15th percentile travel time (Equation 2). Two radius values were examined: 1-mile and 2-miles from the work zone segment's beginning location.

6. Delays Computed Using Historical Data

The delay measures previously defined were calculated for the work zones identified. Table 4 shows the delay values for less than one day and more than one day duration work zones on the I-270, I-70, and MO 141 corridors.

Table 4. Travel time delay for the study corridors

Route	Duration	Average TT delay using historical average travel time (min/mile/WZ)			Average TT delay using 15th percentile travel time (min/mile/WZ)		
		WZ	1UPS	2UPS	WZ	1UPS	2UPS
I-270	≤ 1 day	0.72	0.15	0.03	0.54	0.19	0.03
I-70	≤ 1 day	0.11	0.13	0.08	0.12	0.14	0.11
MO 141	≤ 1 day	0.19	0.44	0.34	0.08	0.28	0.29
I-270	≤ 1 day	0.15	0.15	0.91	0.25	0.26	0.22
I-70	≤ 1 day	0.13	0.11	0.25	0.12	0.14	0.14
MO 141	≤ 1 day	0.42	0.44	0.35	0.59	0.74	0.60

Delay values are reported using both historical average travel times (HATTs) and 15th percentile travel times. Table 4 shows that historical and 15th percentile delays differ in practice. Table 4 also shows that the delays across the three segments (WZ, 1UPS, 2UPS) do not have a set pattern.

In addition to the average delays shown earlier in Table 3, histograms showing the delay distributions were also plotted as shown in Figures 11 through Figure 16.

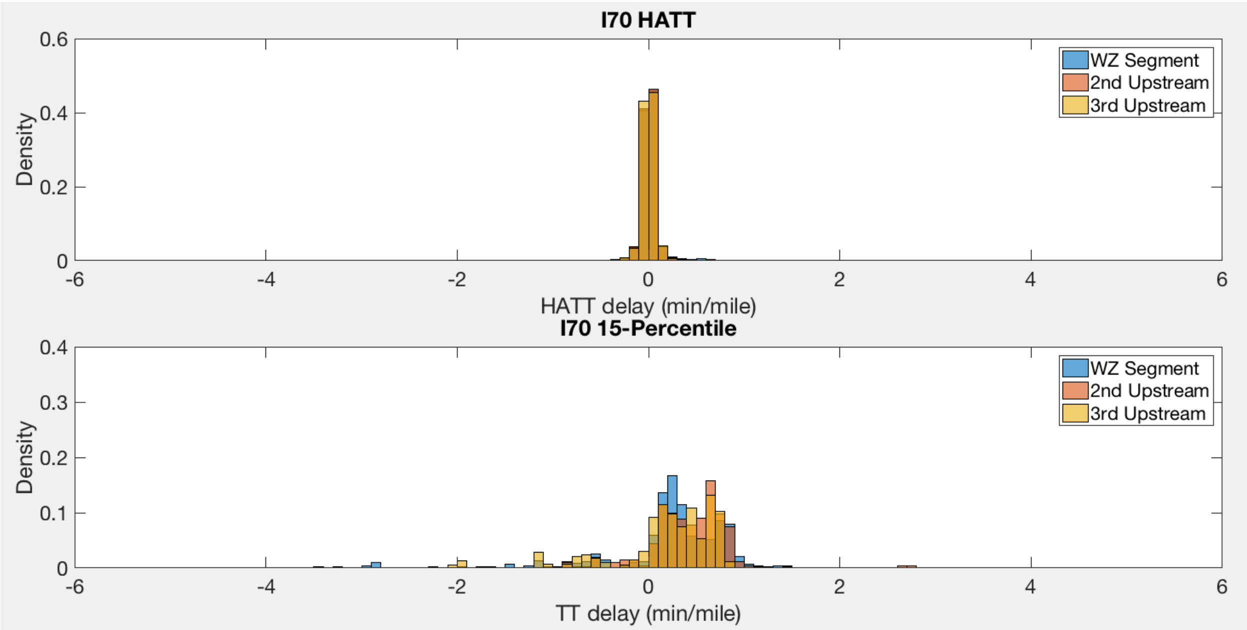


Figure 11. Histogram for HATT and reference TT for I-70 (one day or less)

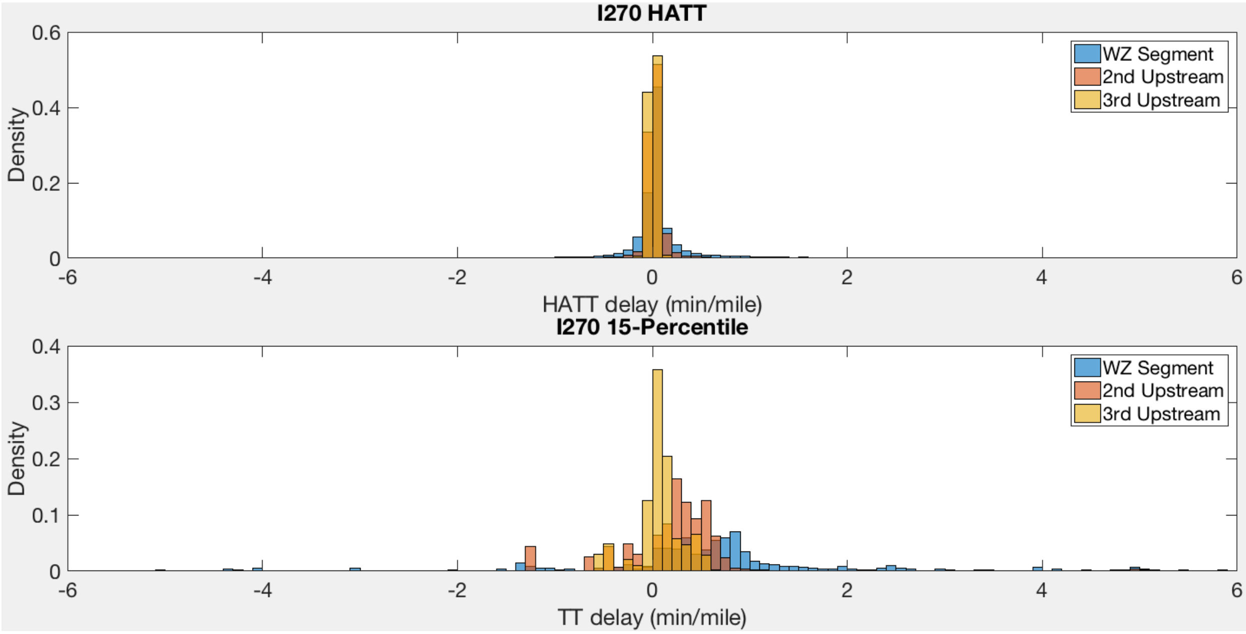


Figure 12. Histogram for HATT and reference TT for I-270 (one day or less)

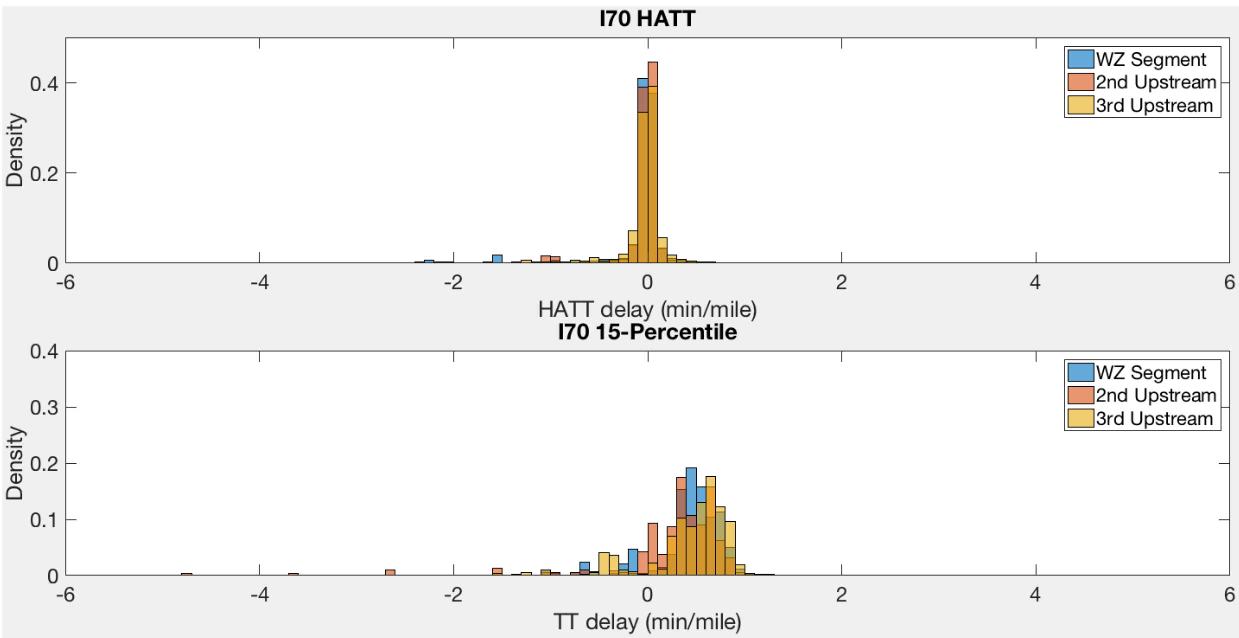


Figure 13. Histogram for HATT and reference TT for I-70 (more than one day)

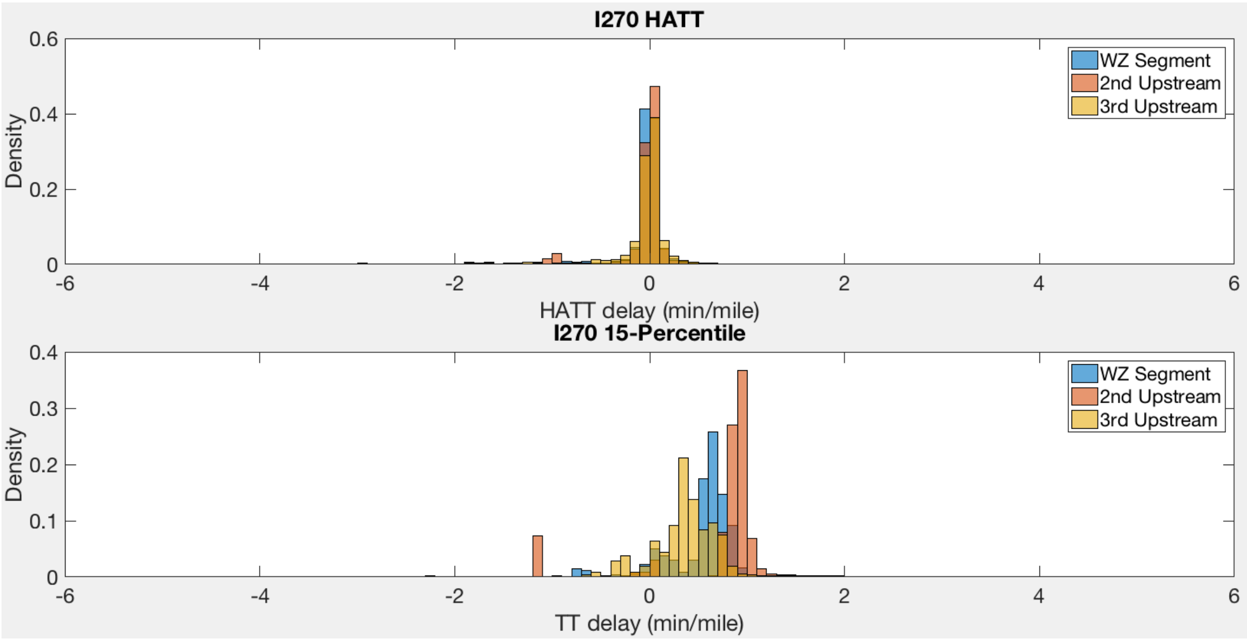


Figure 14. Histogram for HATT and reference TT for I-270 (more than one day)

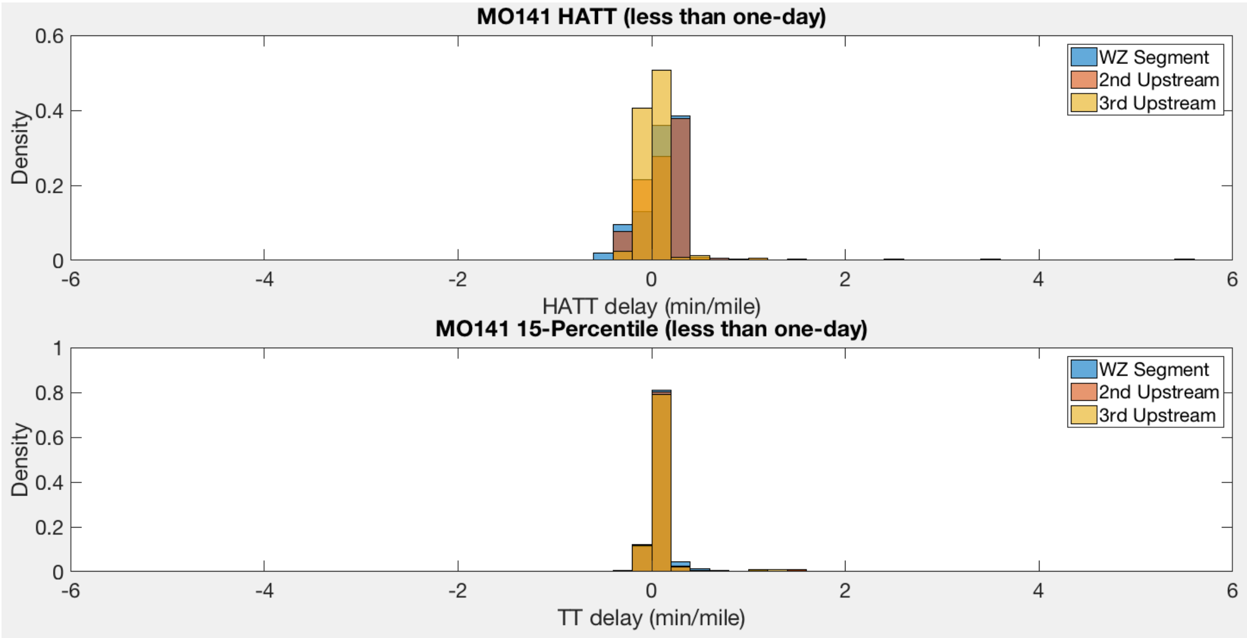


Figure 15. Histograms for MO 141 travel times (one day or less)

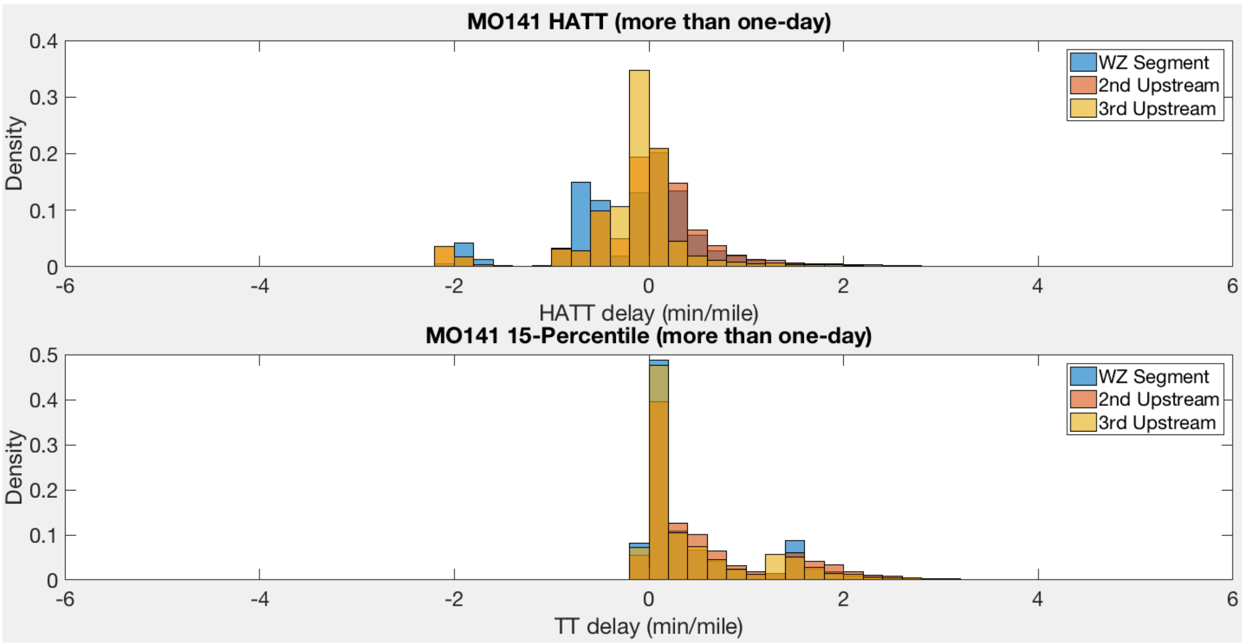


Figure 16. Histograms for MO 141 travel times (more than one day)

7. Delays on Adjacent Road Segments

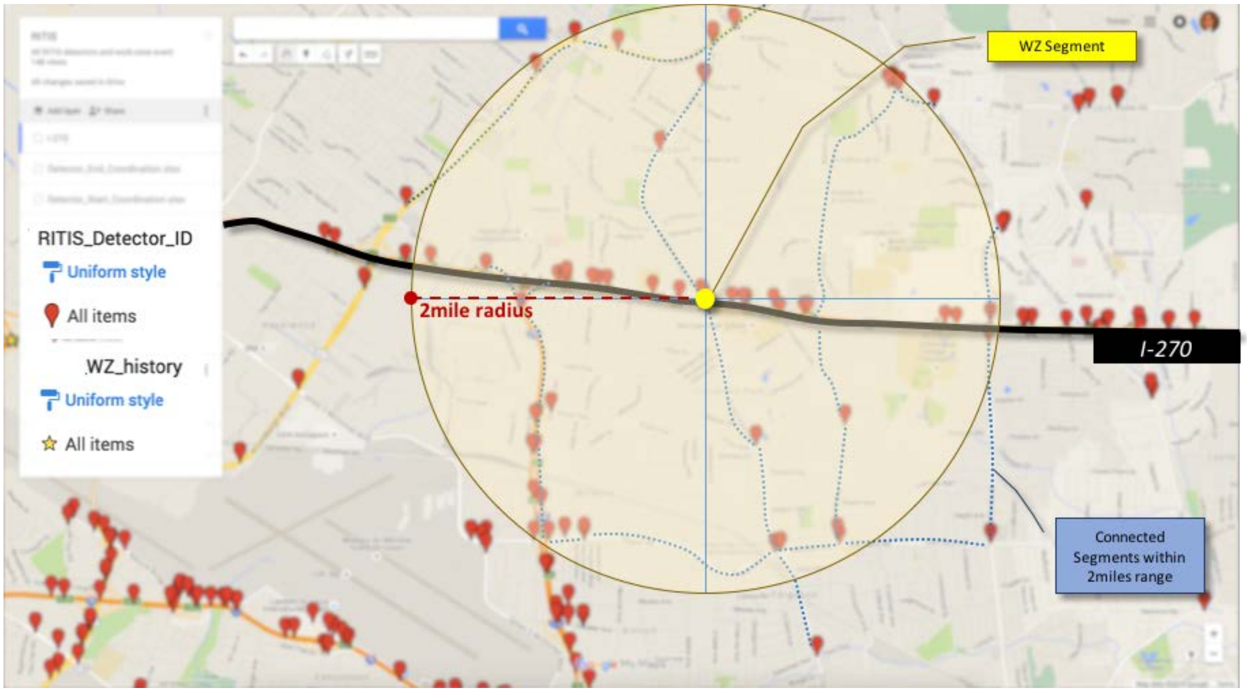
For every work zone included in the sample discussed earlier (2014 and 2015 work zones on I-270, I-70, and MO 141), all road segments (for which travel times were measured) within a 1-mile and 2-mile radius of the work zone were identified. The spherical law of cosines that computes distance between two points using their latitude and longitude, as shown in Equation 3, was adopted to accomplish this.

Spherical law of cosines

$$distance = \mathrm{acos}(sin\varphi_1 \times sin\varphi_2 + cos\varphi_1 \times cos\varphi_2 \times cos\Delta\lambda) \times R \quad \textbf{(3)}$$

Where, φ_1 = latitude of work zone location
φ_2 = latitude of segment *i*
$\Delta\lambda$ = longitude of segment *i* - longitude of work zone location
R = desired distance

Figure 17 shows an example involving a 2-mile radius around a work zone on I-270.



Map data ©2017 Google

Figure 17. Identifying road segments within a certain radius of the work zone segment (example of I-270 route)

Table 5 shows the resulting delays using a 1-mile and 2-mile radii. One expected pattern was that delays were shorter for the 2-mile radius compared to the 1-mile radius, as congestion was farther away from the work zone.

Table 5. Delays for segments within 1-mile and 2-mile radius of the work zones

Radius around work zone segment	Duration	Average TT delay with HATT (min/mile/WZ)	Average TT delay with HMTT (min/mile/WZ)	MAX TT delay with HATT (min/mile/WZ)	MAX TT delay with HMTT (min/mile/WZ)
1mile - all	≤ 1 day	0.10	0.11	0.63	0.64
2miles - all	≤ 1 day	0.09	0.10		
1mile - I-270	≤ 1 day	0.095	0.101	0.635	0.642
2miles - I-270	≤ 1 day	0.080	0.084	0.249	0.265
1mile - I-70	≤ 1 day	0.104	0.122	0.410	0.555
2miles - I-70	≤ 1 day	0.097	0.109	0.322	0.374
1mile - all	> 1 day	0.42	0.17	2.58	0.61
2miles - all	> 1 day	0.21	0.16		
1mile - I-270	> 1 day	0.378	0.220	0.988	0.403
2miles - I-270	> 1 day	0.188	0.205	0.371	0.327
1mile - I-70	> 1 day	0.462	0.109	2.584	0.612
2miles - I-70	> 1 day	0.226	0.102	2.584	0.229
1mile - all	All	0.60	0.74	2.85	3.38
2miles - all	All	0.22	0.27		

TRAVEL DELAY PREDICTION MODEL

A travel time prediction model can be used to estimate travel times for planned work zones at sites that may not have sufficient historical work zone data. This chapter explains the procedure used to develop a travel time prediction model based on data from work zone sites on I-70, I-270, and MO 141 including travel times (up to 3 weeks), speed profiles (up to 3 weeks), work zone and upstream segment lengths, lane closure information, and work zone schedule. The predicted travel times were then utilized to compute delays.

1. Random Forests

The Random Forests statistical technique is commonly used for performing regression and classification (Breiman 2001). A single decision tree maps the input data (e.g., location, time, type of work zone) to a prediction, such as travel time. A forest refers to many decision trees that are developed and analyzed. By averaging the prediction from several trees instead of one tree, the problem of a single tree being sensitive to training set noise is mitigated.

In recent research conducted by Hou et al. (2015), Random Forests were shown to be a good technique to predict traffic conditions in work zones. Random Forests outperformed three other machine learning methods (multilayer feedforward neural networks, regression tree, and nonparametric regression) in predicting traffic flow and speed for planned work zone events. Consequently, this project employed the Random Forests technique to predict travel times for work zones. An introduction to regression trees and Random Forests can be found in Hou et al. (2015).

Figure 18 shows the general process of developing a Random Forests model and includes the following steps: initialization, sampling, tree growing, criteria checking, and ensemble generation (i.e., combining multiple trees).

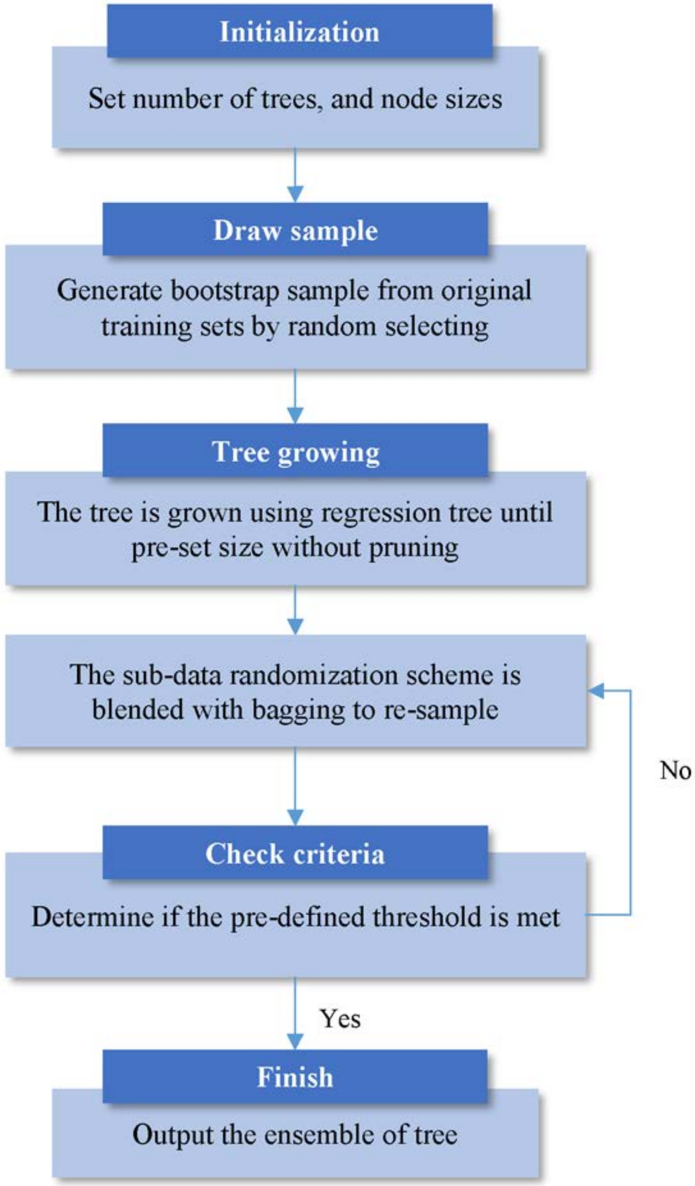


Figure 18. Overview of Random Forests

The developed model can then be used for prediction. To predict a test data case, data are pushed down all the regression trees. Each tree produces a predicted traffic flow. The end result is the average of the predicted traffic flows of all trees. Random Forests constructs a measure of variable importance to help the user understand the mechanism of the prediction process and to eliminate less important variables (Hastie et al. 2009).

Some Random Forests parameters include the total number of predictors, p, the selected predictors, m, and the node size, i.e., tree complexity. Breiman (2001) recommends using $m = p/3$ and a minimum node size of five for regression applications.

2. Building a Travel Time Prediction Model

The model development framework is shown in Figure 19.

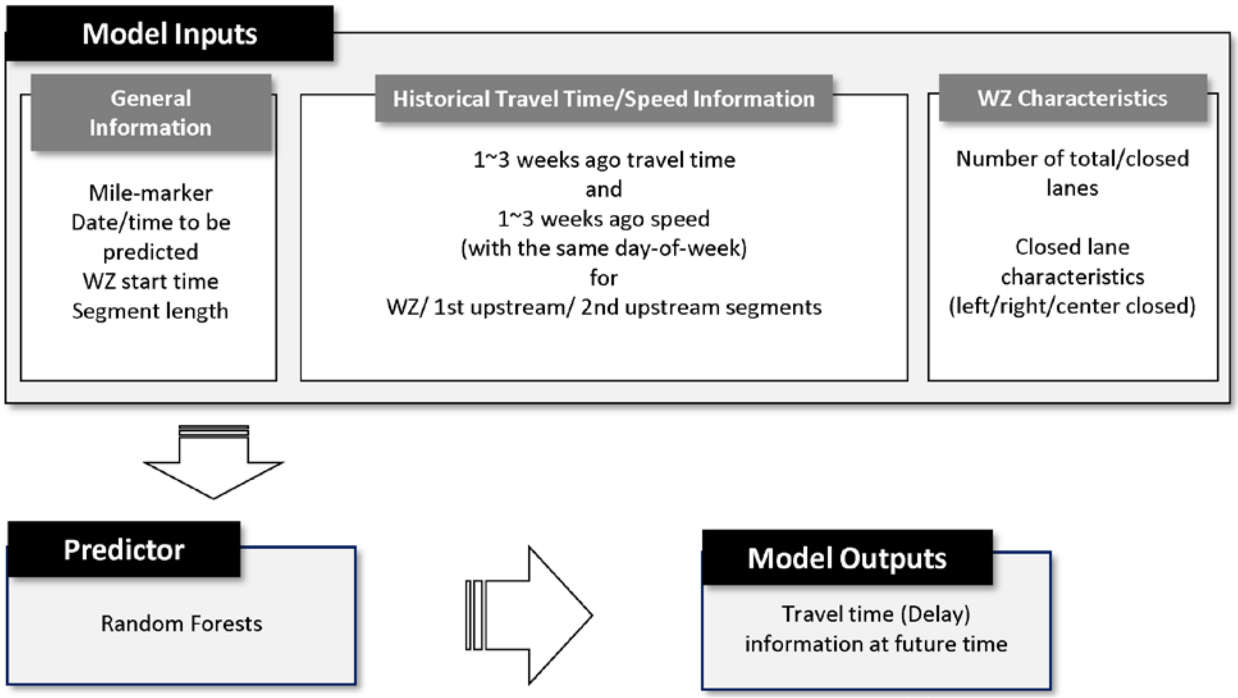


Figure 19. Overall framework of the travel time prediction model

Data describing the work zone is inputted and used in conjunction with historical data. The Random Forests model then produces estimates of the future travel time delay. A total of 27 variables were used in model development. Table 6 shows that these variables included general information, segment-specific information for three segments, and work zone characteristics. The input data were divided randomly into training (75%) and testing (25%) data, as is typical in modeling.

Table 6. Variables used in the prediction model

Categories	Variable Name	Descriptions
General Information	LOCATION	Location ID at RITIS
	DATE	Prediction date to be predicted
	StartTIME	WZ start time to be predicted
	SegLen_UP2	Segment length for 2nd Upstream segment (mile)
	SegLen_UP1	Segment length for 1st Upstream segment (mile)
	SegLen_WZ	Segment length where WZ presented (mile)
WZ Segment	TT_1WEEKAGO_WZ	1 week ago travel time at WZ segment location
	TT_2WEEKAGO_WZ	2 week ago travel time at WZ segment location
	TT_3WEEKAGO_WZ	3 week ago travel time at WZ segment location
	SPD_1WEEKAGO_WZ	1 week ago speed at WZ segment location
	SPD_2WEEKGO_WZ	2 week ago speed at WZ segment location
	SPD_3WEEKAGO_WZ	3 week ago speed at WZ segment location
1st Upstream from WZ Segment	TT_1WEEKAGO_2UP	1 week ago travel time at 1st Upstream location
	TT_2WEEKGO_2UP	2 week ago travel time at 1st Upstream location
	TT_3WEEKAGO_2UP	3 week ago travel time at 1st Upstream location
	SPD_1WEEKAGO_2UP	1 week ago speed at 1st Upstream location
	SPD_2WEEKGO_2UP	2 week ago speed at 1st Upstream location
	SPD_3WEEKAGO_2UP	3 week ago speed at 1st Upstream location
2nd Upstream from WZ Segment	TT_1WEEKAGO_3UP	1 week ago travel time at 2nd Upstream location
	TT_2WEEKGO_3UP	2 week ago travel time at 2nd Upstream location
	TT_3WEEKAGO_3UP	3 week ago travel time at 2nd Upstream location
	SPD_1WEEKAGO_3UP	1 week ago speed at 2nd Upstream location
	SPD_2WEEKGO_3UP	2 week ago speed at 2nd Upstream location
	SPD_3WEEKAGO_3UP	3 week ago speed at 2nd Upstream location
WZ Characteristics	Closed Lanes	Closed lane type (i.e., right/left/center lane close)
	Total Number of lanes	Total number of lanes for the segment
	Number of Closed Lanes	Total number of closed lanes for the segment

For work zones on interstates, two Random Forests models were developed: one model for work zones with durations equal to or shorter than one day and one model for work zones with durations longer than one day. Two models were used instead of one because shorter duration work zones are fundamentally different than other work zones.

These models were developed using data from 253 work zones (≤1 day duration) and 513 work zones (>1 day duration) that occurred on I-70 and I-270 over a period of 22 months, from January 2014 through October 2015. The data were divided into training and testing sets as previously discussed. Random Forests models and baseline models were developed using these data.

The researchers developed two baseline models. The first baseline model used the average of travel time at the same location and time in the prior three weeks (same as HATT previously discussed) as an estimate for the travel time with the work zone present. The second baseline model used travel time from one previous week instead of three weeks.

The prediction accuracies, root mean square error (RMSE), mean average error (MAE), and mean average percent error (MAPE), of the three models are shown in Table 7.

Table 7. Results for travel time prediction (interstates)

Travel Time prediction (min)	Duration	Random Forests			Baseline (3 weeks average)			Baseline (1 week only)		
		WZS	1UPS	2UPS	WZS	1UPS	2UPS	WZS	1UPS	2UPS
RMSE	≤ 1 day	0.23	0.17	0.08	0.45	0.33	0.11	0.46	0.25	0.13
MAE	≤ 1 day	0.06	0.05	0.02	0.11	0.08	0.04	0.12	0.07	0.04
MAPE	≤ 1 day	4.85%	4.56%	4.04%	7.41%	6.81%	6.29%	8.89%	9.24%	8.09%
RMSE	> 1 day	0.08	0.13	0.12	0.14	0.21	0.21	0.18	0.25	0.26
MAE	> 1 day	0.02	0.03	0.04	0.04	0.06	0.06	0.05	0.06	0.07
MAPE	> 1 day	3.95%	4.15%	4.18%	6.93%	6.97%	7.16%	7.97%	8.04%	8.31%

Across all measures and for both work zone and upstream segments, the Random Forests model outperformed the two baseline approaches. A graphical comparison is shown in Figure 20 for one day or less work zones and in Figure 22 for more than one day work zones. The importance of different variables in the prediction model are also plotted in Figures 21 and 23. The historical travel times (i.e., from one, two, and three weeks prior) exhibited the greatest impacts on the prediction accuracy.

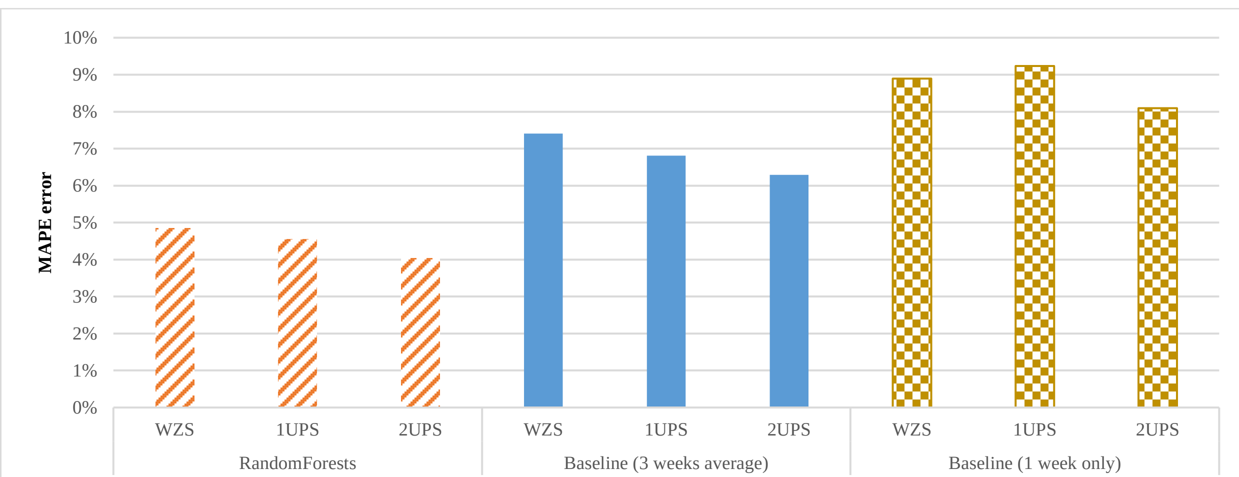


Figure 20. Random Forests and baseline predictions for one day or less work zones (interstates)

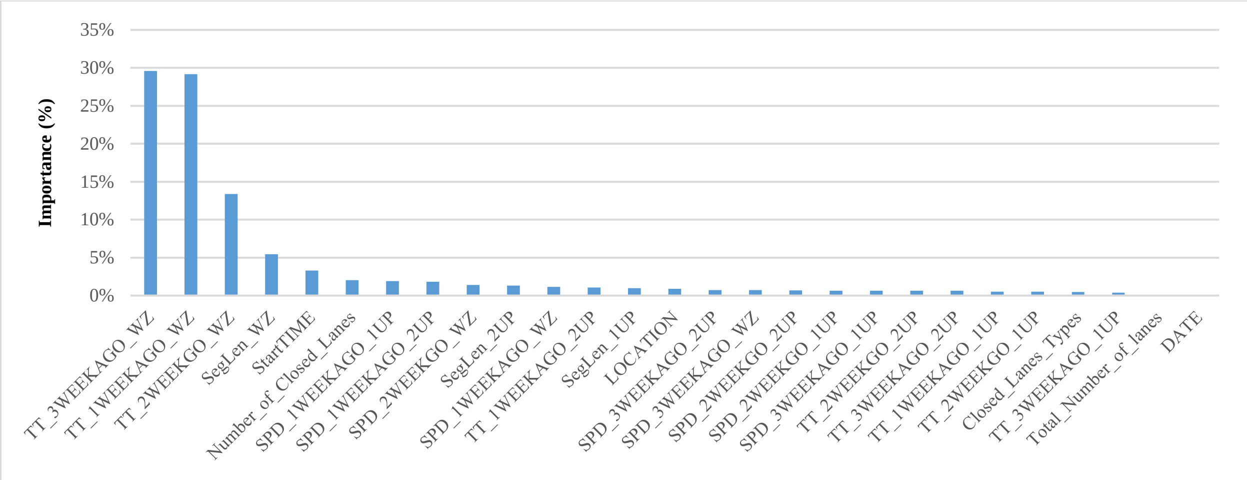


Figure 21. Importance of variables in the prediction model for one day or less work zones (interstates)

Figure 22. Random Forests and baseline predictions for more than one day work zones (interstates)

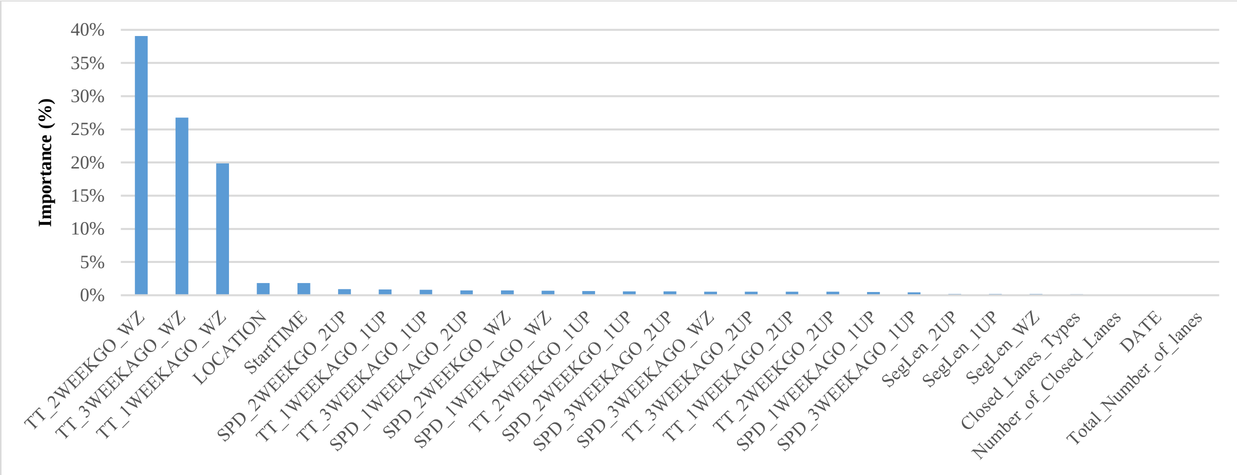


Figure 23. Importance of variables in the prediction model for more than one day work zones (interstates)

The researchers also developed prediction models for the MO 141 arterial work zones. Data from 16 work zones events that occurred from January 2014 through October 2015 were used for model development and testing. The Random Forests and baseline prediction accuracies are shown in Table 8 and Figure 24. Again, the Random Forests outperformed both baseline predictions.

Table 8. Results for travel time prediction (arterial)

Travel Time prediction (min)	Random Forests			Baseline (3 weeks average)			Baseline (1 week only)		
	WZS	1UPS	2UPS	WZS	1UPS	2UPS	WZS	1UPS	2UPS
RMSE	0.12	0.12	0.19	0.27	0.33	0.46	0.30	0.30	0.47
MAE	0.05	0.04	0.07	0.12	0.11	0.16	0.13	0.10	0.16
MAPE	3.92%	4.71%	3.87%	9.81%	10.73%	9.42%	9.46%	10.79%	9.15%

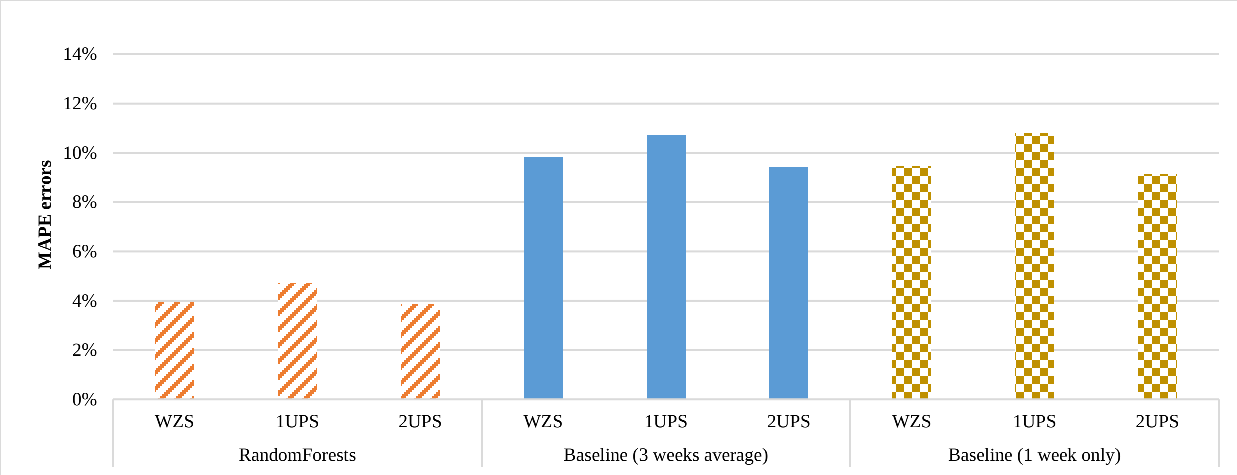


Figure 24. Random Forests and baseline predictions (arterial)

The variable importance chart for MO 141 is shown in Figure 25.

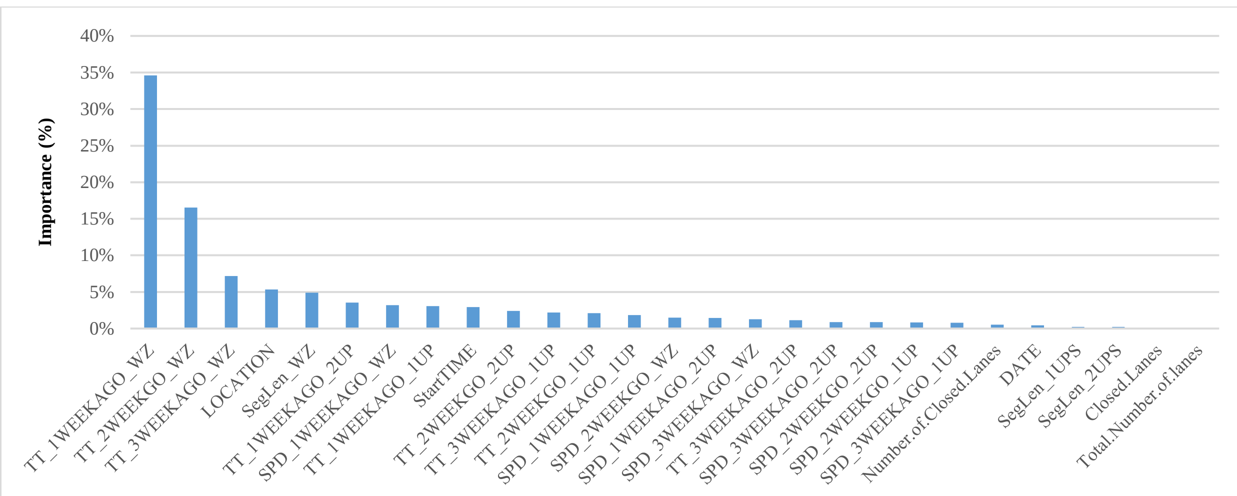


Figure 25. Importance of variables in the prediction model (arterial)

Similar to interstates, the historical travel times at the work zone site (i.e., from one, two, and three weeks prior) proved to be the variable with greatest impact on the accuracy of work zone travel times.

DEVELOPMENT OF PROTOTYPE TOOL

1. Prototype Architecture

The research team developed a prototype of the data-driven traffic assessment tool using data from work zones in the St. Louis region. MoDOT can expand use of this prototype tool to other regions using region-specific work zone and traffic data. The architecture of the prototype tool is shown in Figure 26.

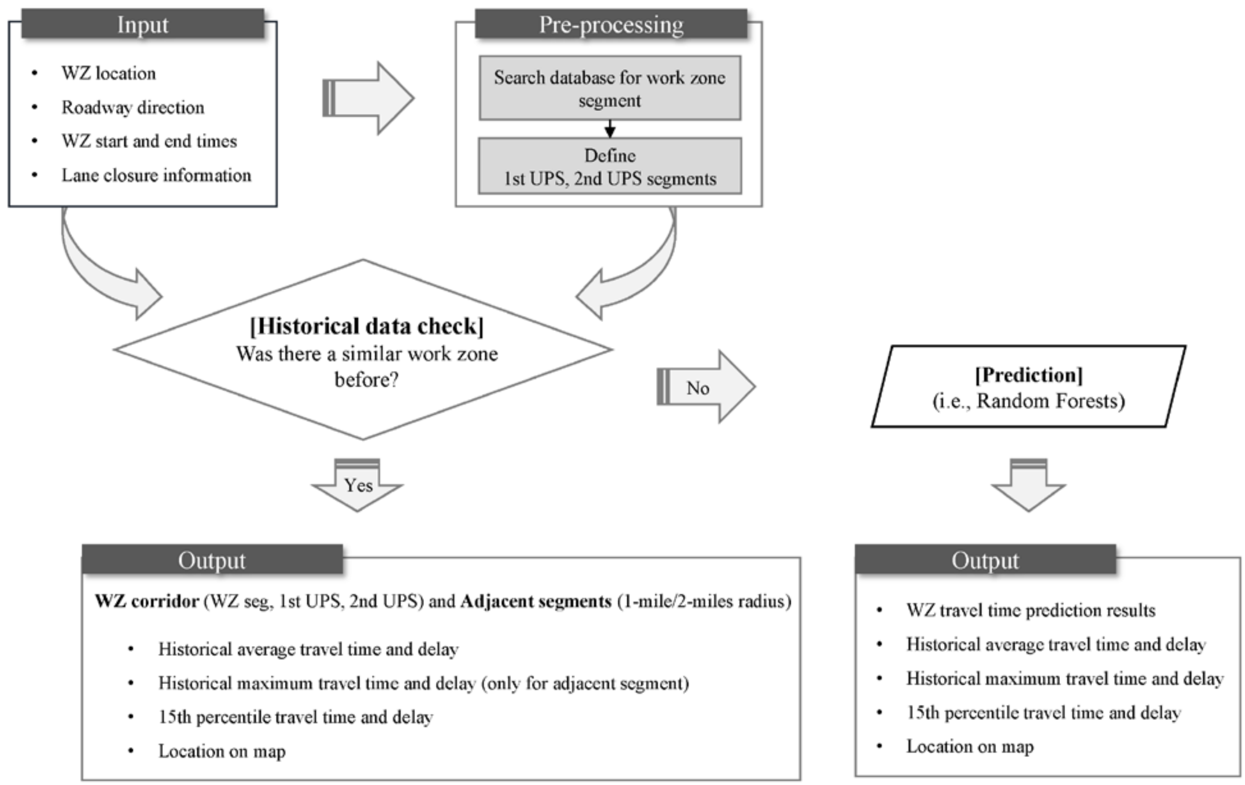


Figure 26. Architecture for the proposed prototype tool

The user enters four types of input information: work zone coordinates, roadway direction, work zone duration, and work zone type. The tool uses this information to mine the historical data to identify any work zones that occurred at the same location in the past from the data available. If a match is found, the data are utilized to generate the expected delay measures (travel time delay based on normal days' historical average travel times and travel time delay based on 15th percentile travel times while the work zone was present) that were previously described. If a match is not found, a delay prediction model, as previously discussed, is used to generate the expected delay measures.

Instructions for installing the tool and a walk-through of the tool's features are provided next.

2. System Requirements

For best performance, the following minimum computational requirements are recommended for use of the prototype.

- RAM: 2 gigabytes or more
- HDD empty space: 2.5 gigabyte or more
- Recommended monitor resolution: 1,920 × 1,080 pixels per inch or higher
- MATLAB Runtime (included in installation file)
- Windows operating systems (Windows 7, 8, or 10)
- Internet connection
- Microsoft Excel
- Google Earth (only to visualize delay plots spatially)

3. Installation

There are two folders: 1_Install and 2_Run_after_Install (see Figure 27).

Figure 27. Folder for installing

The first folder, 1_Install, is for installing the prototype tool and MATLAB Runtime environment

The installation file for this software tool, DDT_Install.exe file under 1_Install folder, and the MATLAB Runtime are installed together (see Figure 28).

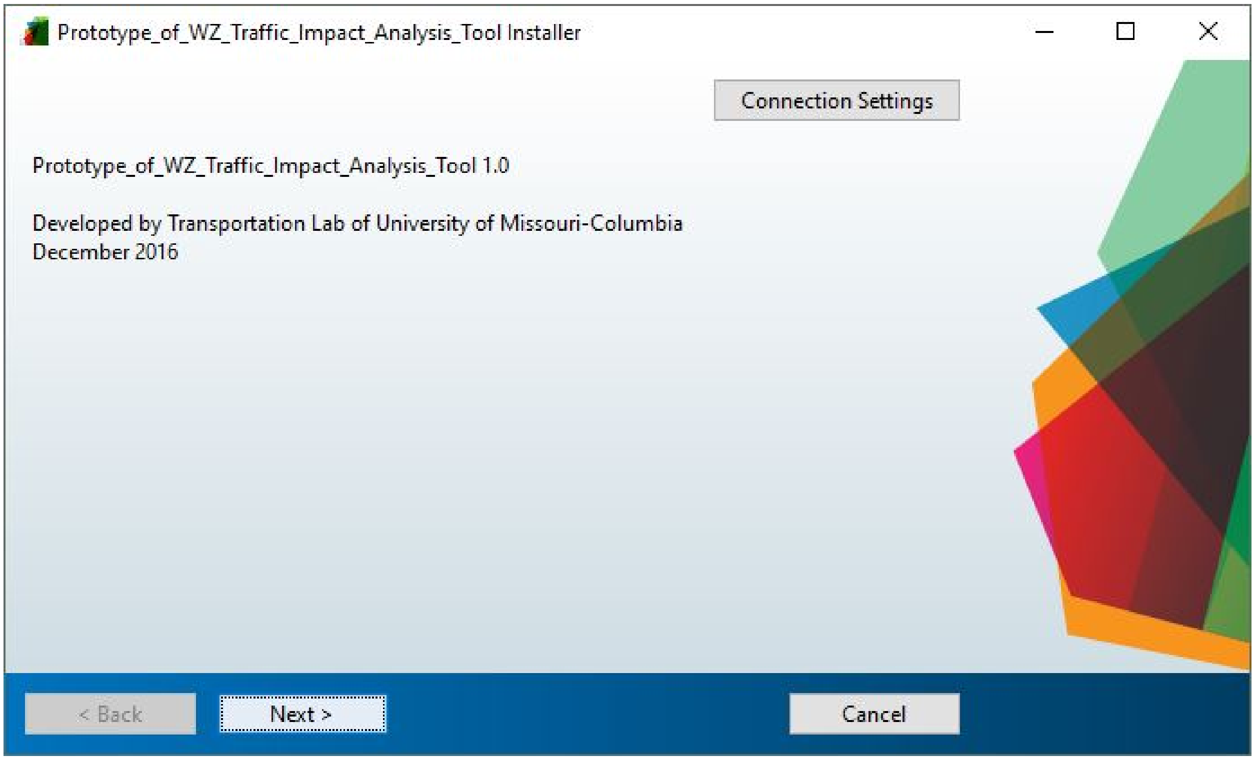


Figure 28. Screenshot of prototype installation

4. Running the Prototype after Installation

Once the installation is complete, a user can run the prototype tool by double clicking the DDT_WZ.exe file located inside the 2_Run_after_Install folder, as shown in Figure 29.

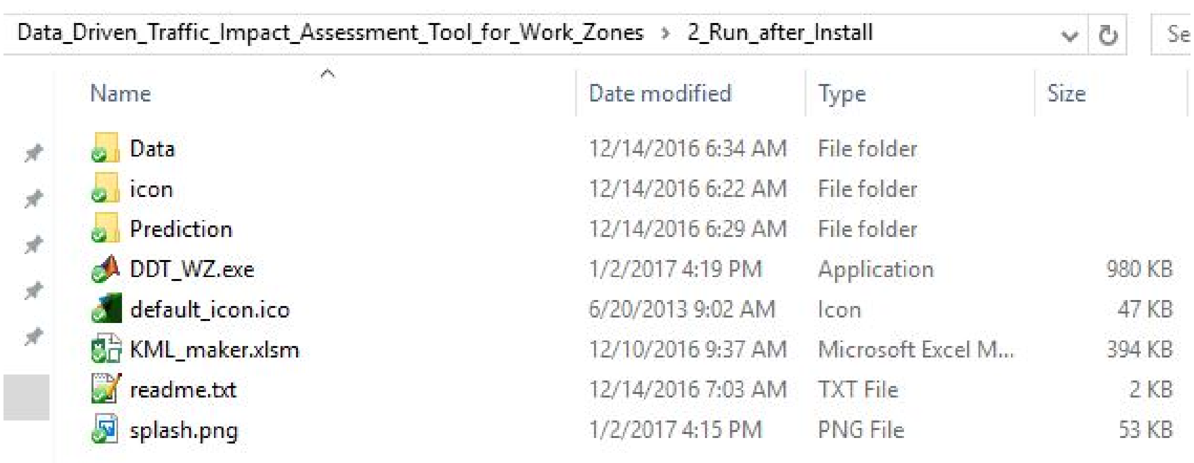
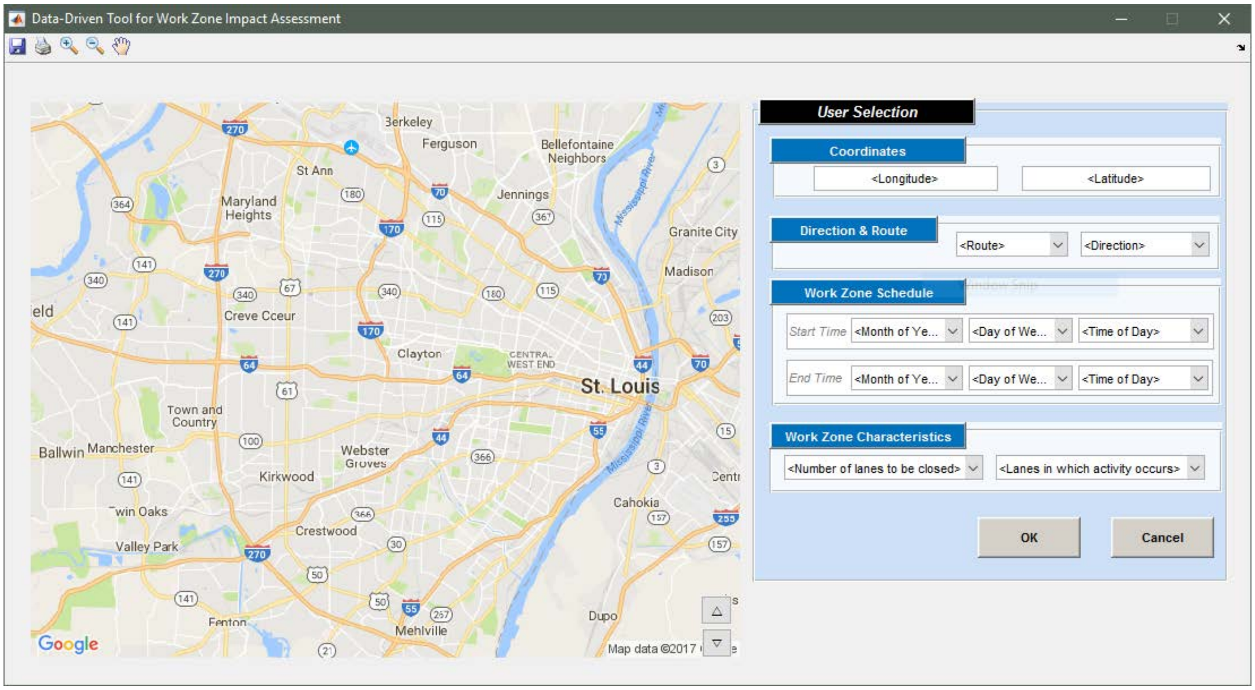


Figure 29. Screenshot for 2_Run_after_Install folder

A screenshot of the tool after it's launched is shown in Figure 30.

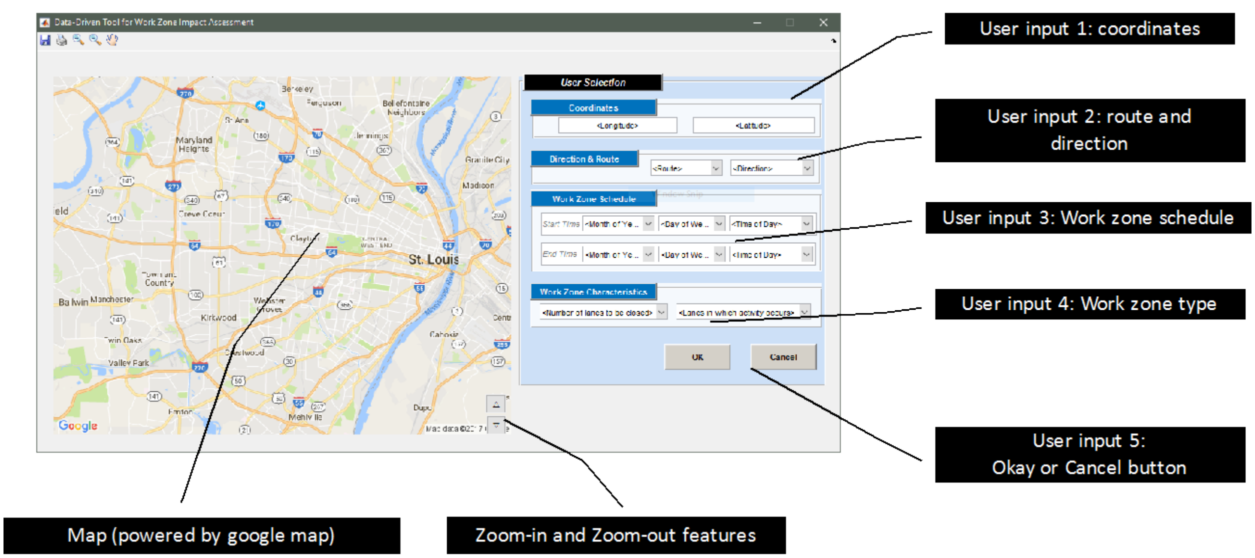


Map data ©2017 Google

Figure 30. Screenshot for DDT_WZ software

5. Prototype Features

The user inputs coordinates, direction, duration, and type for a planned work zone as indicated by the callouts on the input window shown in Figure 31.



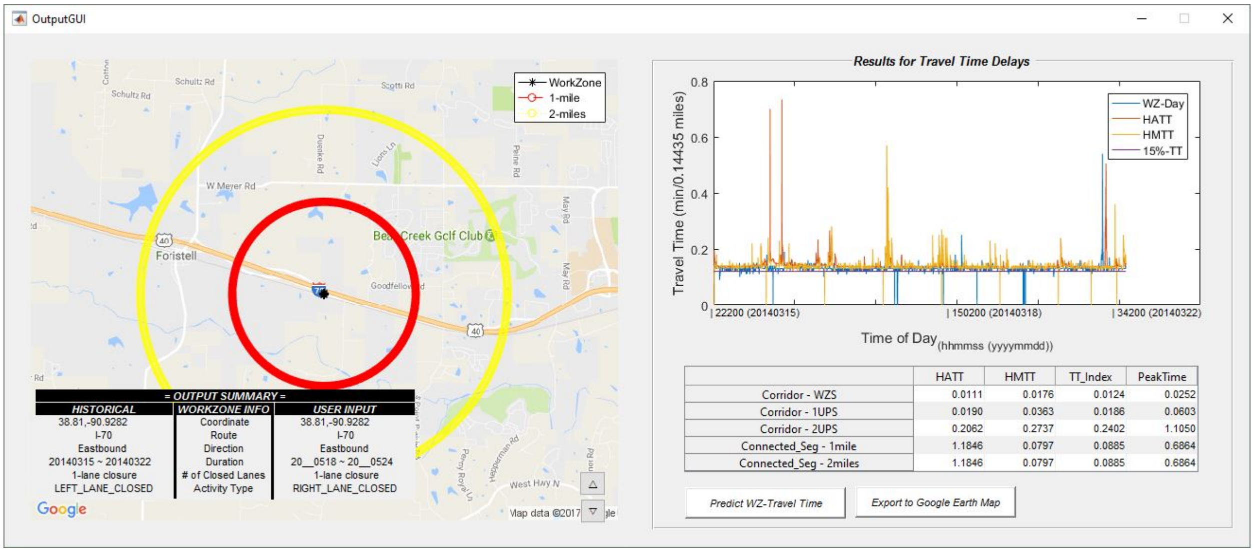
Map data ©2017 Google

Figure 31. Screenshot for DDT_WZ graphical user interface

The location of the work zone is entered as latitude and longitude on the Coordinates tab. A dropdown menu was created from which a user can select the route and its direction. Work zone lane closure information and activity types can also be selected from drop-down menus.

6. Output Features

After entering all inputs, the user then clicks the OK button to run the tool. A screenshot of the output window is shown in Figure 32.



Map data ©2017 Google

Figure 32. Screenshot for output graphical user interface

The left side of Figure 32 shows the work zone location on a map and the right side plots the travel time measures for the work zone segment. The table below the plot reports the delays (in minutes) for work zone segment, upstream segments, and adjacent segments impacted by the work zone. On the left side of the output window, the red circle shows the 1-mile boundary around work zone and the yellow circle shows the 2-mile boundary. A summary of the input data entered by the user is shown in a table at the bottom left of the screen.

The Predict WZ-Travel Time button enables a user to predict the travel time for a planned work zone when there is no historical data for that location. The prediction is made using a trained Random Forests model discussed previously. Once a user clicks the Predict WZ-Travel Time button, the prototype runs additional scripts in the R program to predict travel times. The successful initiation window of the additional scripts in R is shown in Figure 33.

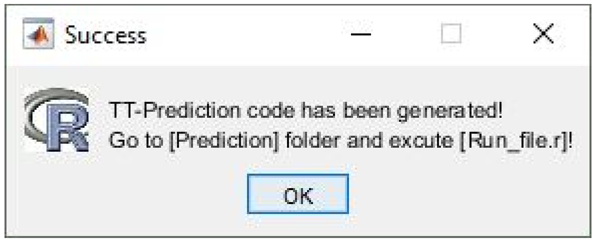


Figure 33. Successful initiation of the Random Forests prediction module

The user clicks on the OK button and can then launch the R software (available in the prediction folder) by double clicking the R-Portable.exe file. The prediction results are shown in the output window (Figure 34).

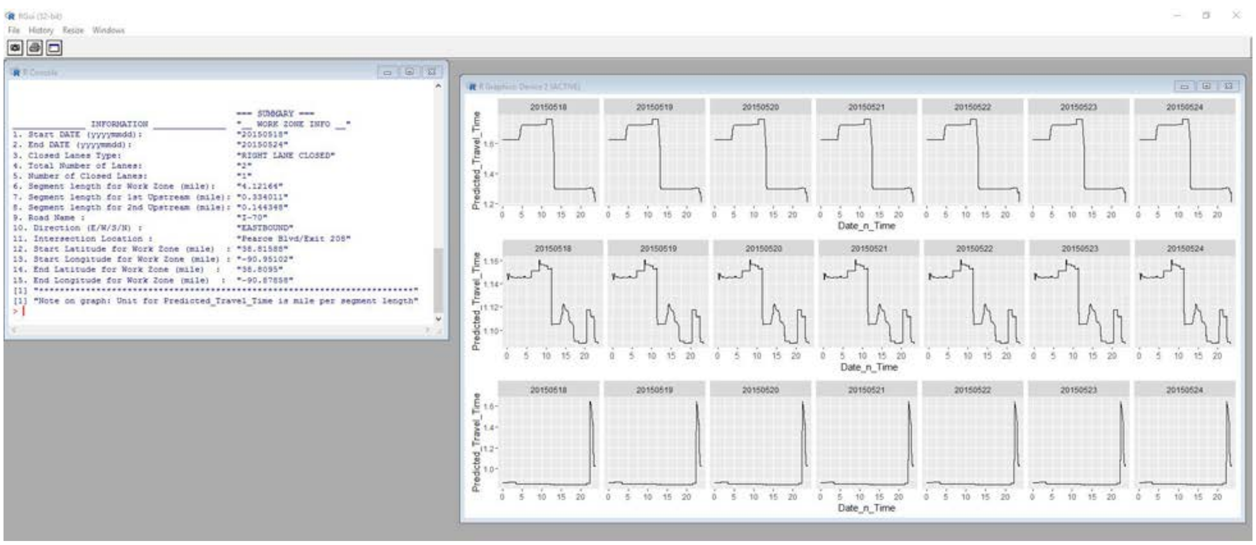


Figure 34. Predicted travel times in R

The left side of the window provides a summary of the input information. On the right side, a series of travel time plots are presented: the top row shows the predicted travel times for the work zone segment, the second row shows the predicted travel times for first upstream segment (1UPS), and the third row shows the predicted travel times for the second upstream segment (2UPS). Additional output files in csv format (i.e., comma-delimited text) are saved in the Results folder.

Finally, the prototype allows a user to export the delay results into Google Earth to better visualize them spatially. To do this, the user clicks on the Export to Google Earth Map button on the bottom right of the prototype's output graphical user interface. This process launches an Excel file and Google Earth program (if installed). A screenshot of the Google Earth visualization is shown in Figure 35.

Figure 35. Spatial visualization of delays in Google Earth

In Figure 35, three consecutive mainstream segments, work zone segment, 1st upstream, and 2nd upstream, are shown in different colors with work zone location outlined in red, 1st upstream outlined in yellow, and 2nd upstream outlined in orange. In addition, adjacent segments within 2 miles are outlined and highlighted in blue. The height of each polygon indicates the travel time delay for that segment; the taller the highlighted polygon, the greater the delay.

CONCLUSIONS

The researchers examined the feasibility of using historical data to develop a data-driven tool for assessing traffic impacts of work zones in this project. The research team used data from 766 freeway work zones (253 work zones with durations up to one day and 513 work zones with durations more than one day) and 16 arterial work zones over a period of 22 months, from January 2014 through October 2015.

A travel time prediction model, using Random Forests, was developed to estimate travel times for work zones at locations that may not have sufficient historical work zone data. The project culminated with the development of a prototype tool that incorporates historical data and prediction models for assessing traffic impacts at work zones.

The metropolitan St. Louis, Missouri region was used as the initial location for demonstrating the feasibility of the tool. When a planned work zone site has historical data available, the tool presents the historical data as the best estimate of the travel time. When historical data is not available for a location, the Random Forests prediction model produces estimates of the travel times.

The accuracies observed for both interstate and arterial work zones were acceptable, under 5% error in the predicted travel times. The scope of the prototype was limited to two interstate corridors and one arterial corridor.

The tool requires four types of input information: work zone location, roadway direction, work zone duration, and work zone type and lane closure information. The tool then makes predictions of travel times with and without work zone to compute the delays.

In the future, the tool can be enhanced in a few ways. First, additional routes from Smart Work Zone Deployment Initiative (SWZDI) states should be included. As shown in this project, travel time and work zone information are the key historical information required to add a corridor to use of the tool. The variability of this historical information among different SWZDI states also needs to be addressed. Second, while this study included work zones that occurred on an arterial, the sample size was smaller than the freeway work zones.

In the future, additional arterial work zones should be added to the tool. Similarly, work zones occurring on other types of roadways such as two lane roads and local roads should also be explored in future research.

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APPENDIX A: HISTOGRAMS OF TRAVEL TIME DELAYS

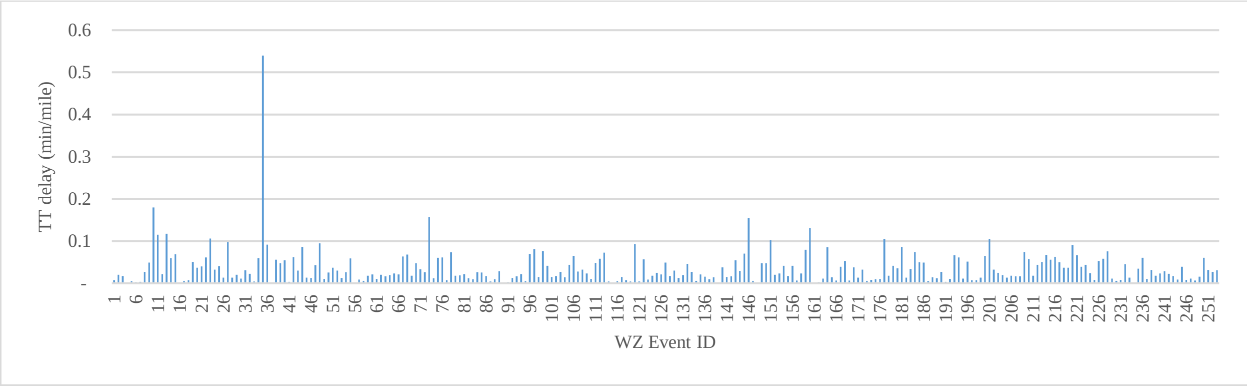

Figure A1. One-mile HATT delay by each WZ event ID of the two interstates (one day or less duration for I-270 and I-70)

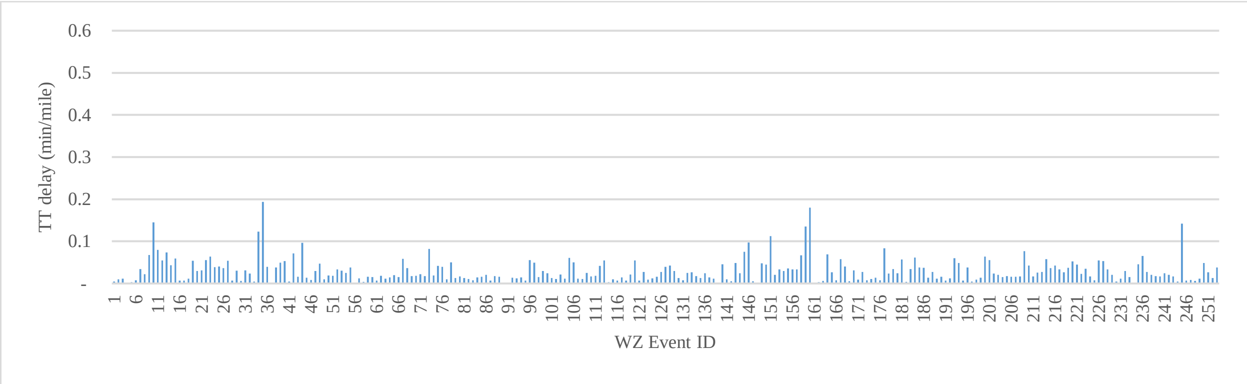

Figure A2. Two-mile HATT delay by each WZ event ID of the two interstates (one day or less duration for I-270 and I-70)

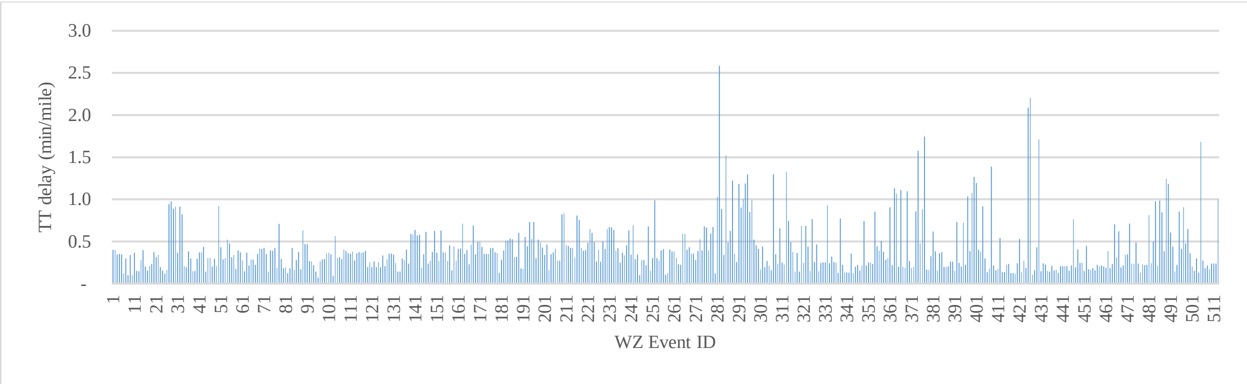

Figure A3. One-mile HATT delay by each WZ event ID of the two interstates (more than one day duration for I-270 and I-70)

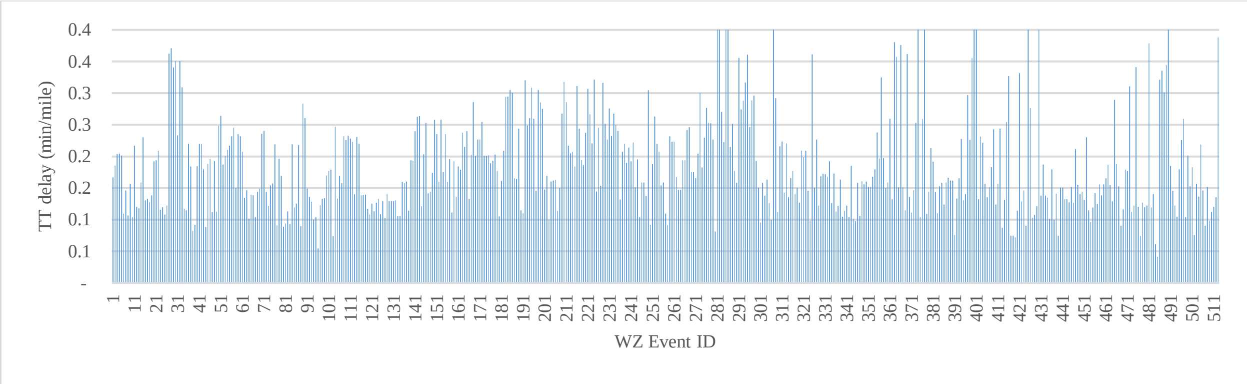

Figure A4. Two-mile HATT delay by each WZ event ID of the two interstates (more than one day duration for I-270 and I-70)

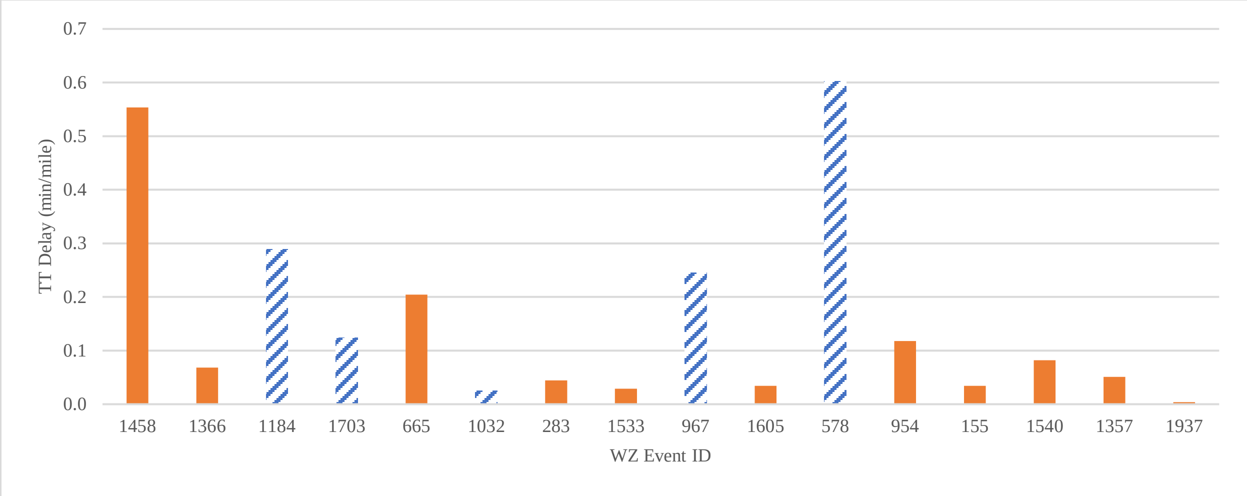

Figure A5. One-mile HATT delay by each WZ event ID (MO 141 arterial)

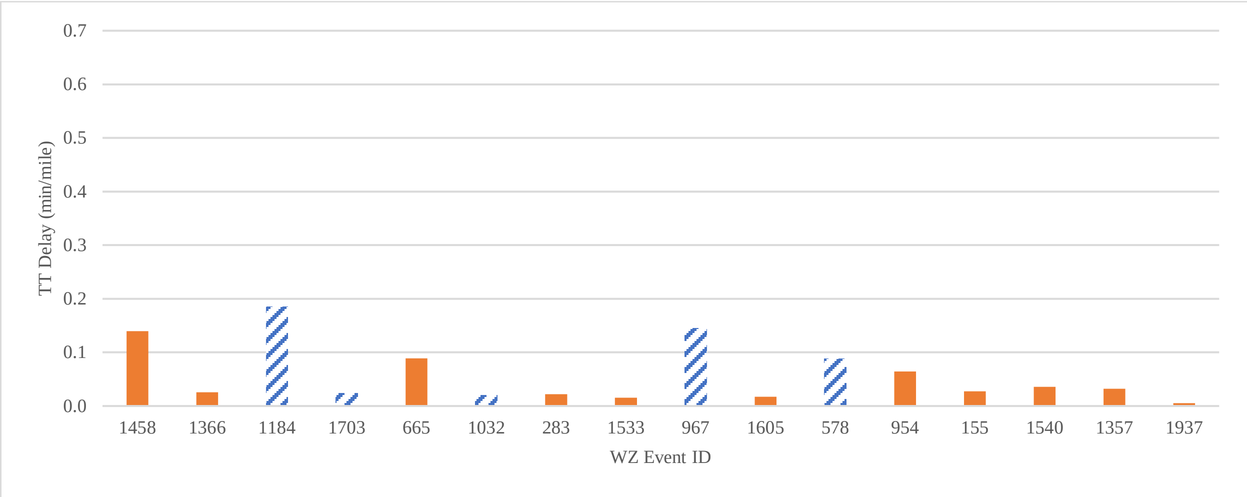

Figure A6. Two-mile HATT delay by each WZ event ID (MO 141 arterial)

APPENDIX B: STANDARD DEVIATIONS OF THE PREDICTION MODEL OUTPUT

Standard deviation (STDEV) and variance for squared errors (SE) and absolute errors (AE) are shown in Table B1, Figure B1, and Figure B2 for each predictor and each segment.

One Day or Less Duration Work Zones

Table B1. Results for STDEV and variance for SE and AE results from TT prediction

	Random Forests			Baseline (3 weeks average)			Baseline (1 week only)		
	WZS	1UPS	2UPS	WZS	1UPS	2UPS	WZS	1UPS	2UPS
STDEV for SE	0.665	0.730	0.192	1.979	1.992	0.216	2.013	0.764	0.240
Variance for SE	0.442	0.533	0.037	3.915	3.967	0.047	4.051	0.583	0.057
STDEV for AE	0.228	0.201	0.084	0.465	0.337	0.108	0.470	0.223	0.121
Variance for AE	0.052	0.040	0.007	0.216	0.114	0.012	0.221	0.050	0.015

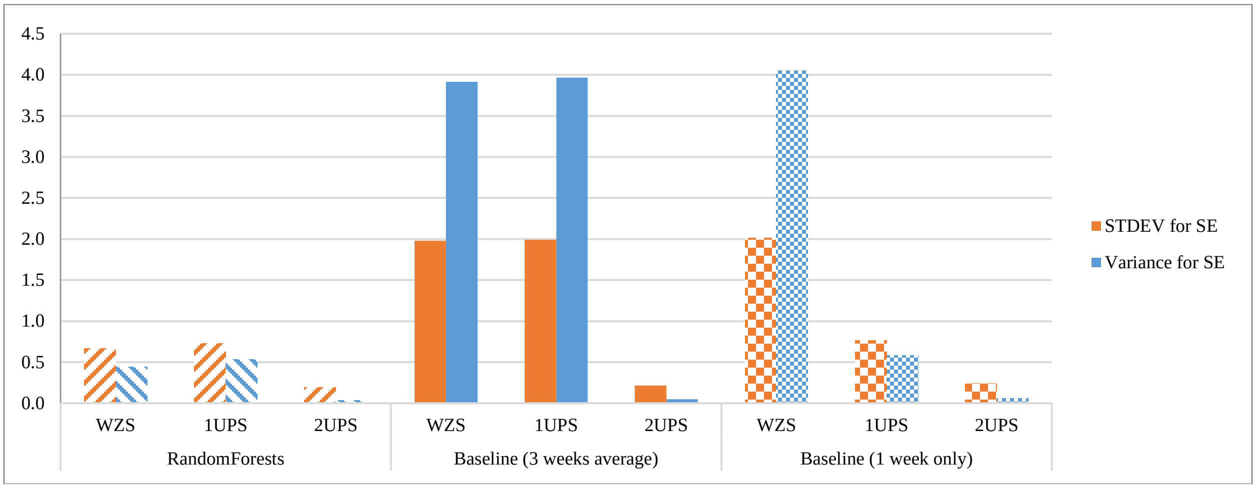

Figure B1. Standard deviation and variance for SE results

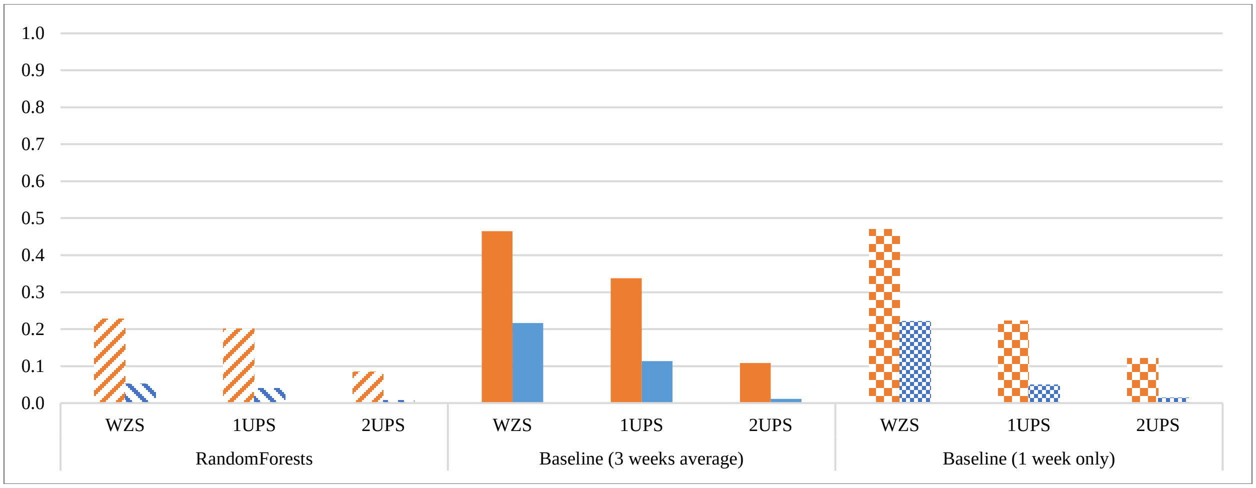

Figure B2. Standard deviation and variance for AE results

More than One Day Duration Work Zones

Table B2. Results for STDEV and variance for SE and AE results from TT prediction

	Random Forests			**Baseline (3 weeks average)**			**Baseline (1 week only)**		
	WZS	**1UPS**	**2UPS**	**WZS**	**1UPS**	**2UPS**	**WZS**	**1UPS**	**2UPS**
STDEV for SE	0.169	0.693	0.365	0.359	1.125	1.343	0.726	1.402	2.313
Variance for SE	0.028	0.481	0.133	0.129	1.265	1.803	0.528	1.966	5.348
STDEV for AE	0.077	0.128	0.118	0.137	0.200	0.204	0.177	0.245	0.2516
Variance for AE	0.006	0.016	0.014	0.019	0.040	0.042	0.031	0.060	0.0633

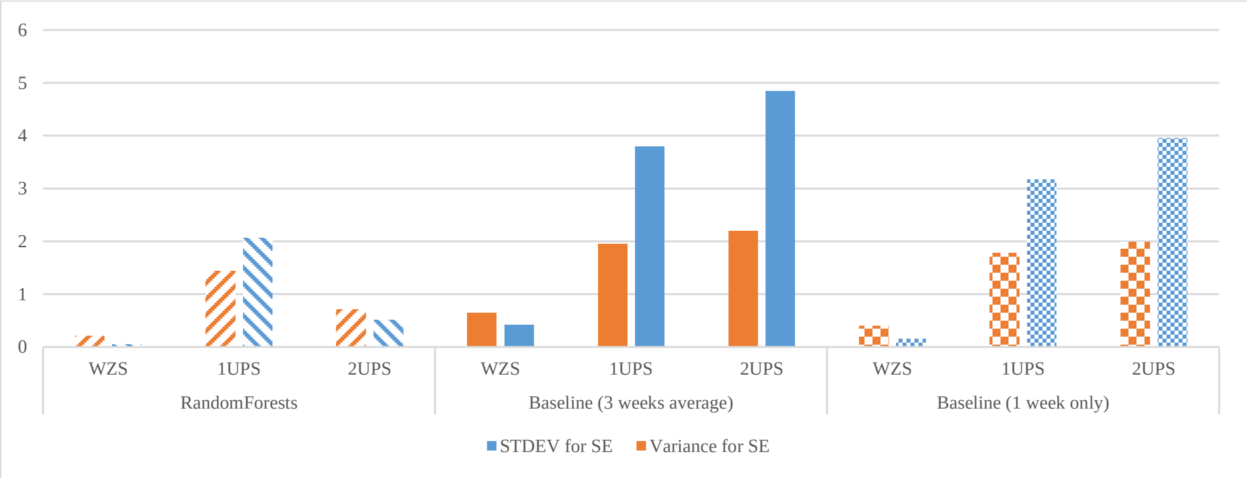

Figure B3. Standard deviation and variance for SE results

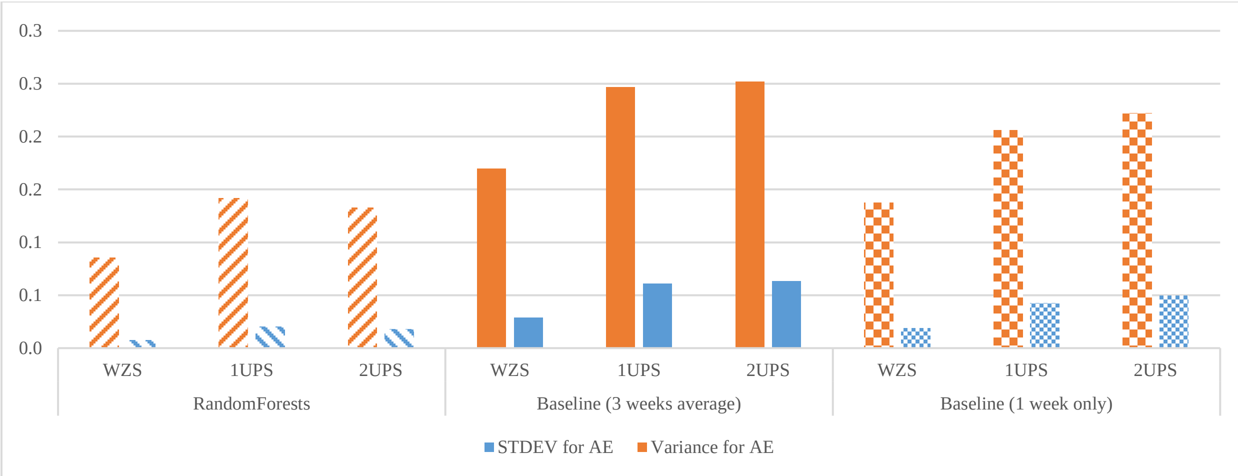

Figure B4. Standard deviation and variance for AE results

Arterial Work Zones

Table B3. Results for STDEV and variance for SE and AE results from TT prediction

	Random Forests			Baseline (3 weeks average)			Baseline (1 week only)		
	WZS	**1UPS**	**2UPS**	**WZS**	**1UPS**	**2UPS**	**WZS**	**1UPS**	**2UPS**
STDEV for SE	0.179	0.131	0.348	0.721	0.787	1.414	1.108	0.675	1.644
Variance for SE	0.032	0.017	0.121	0.519	0.620	1.999	1.228	0.456	2.702
STDEV for AE	0.112	0.113	0.183	0.236	0.306	0.429	0.276	0.283	0.447
Variance for AE	0.013	0.013	0.034	0.056	0.094	0.184	0.076	0.080	0.200

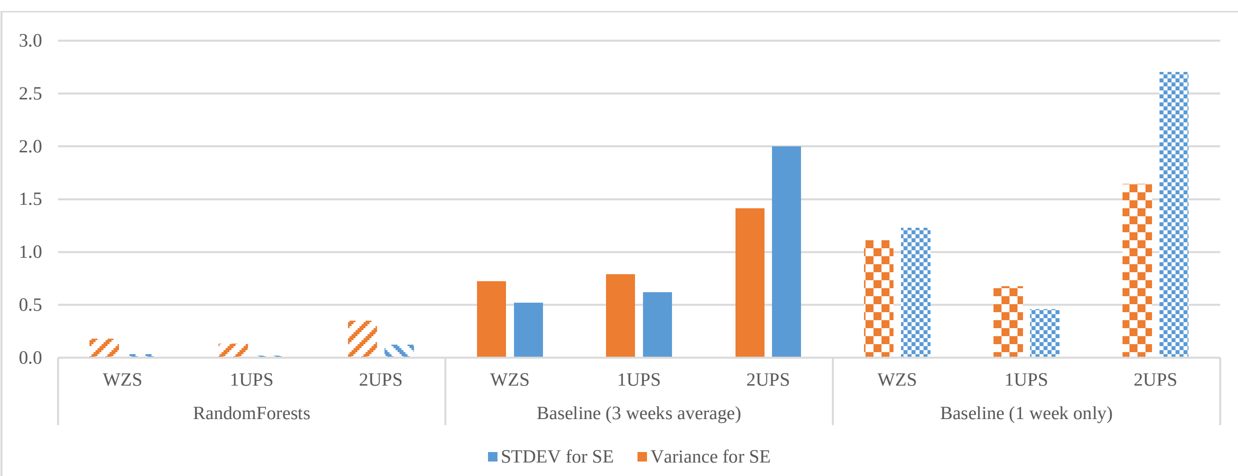

Figure B5. Standard deviation and variance for SE results

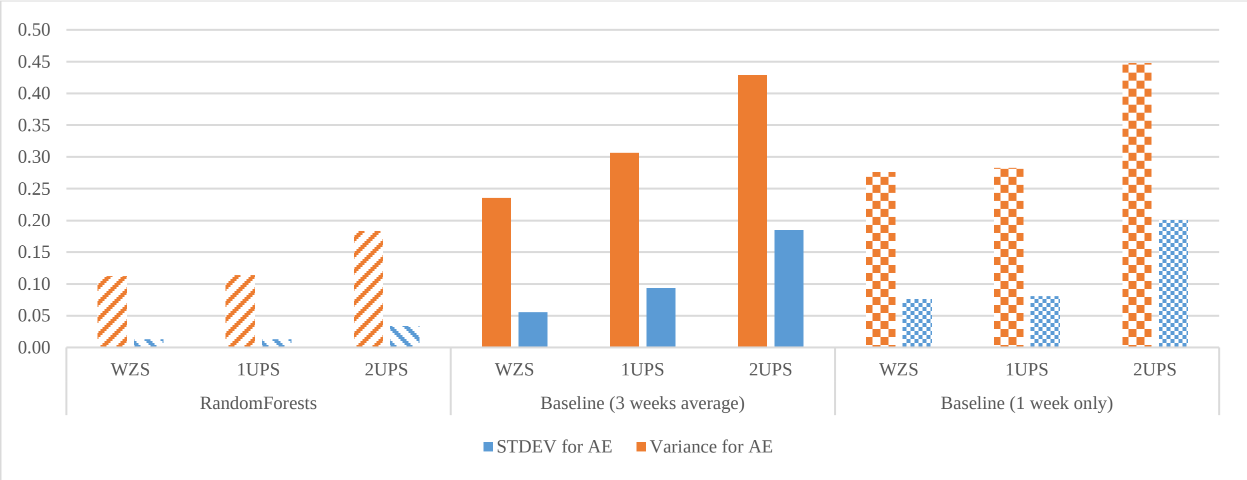

Figure B6. Standard deviation and variance for AE results