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MARYLAND DEPARTMENT OF TRANSPORTATION
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RESEARCH REPORT

WORK ZONE PERFORMANCE MONITORING APPLICATION DEVELOPMENT

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The Federal Highway Administration (FHWA) requires state transportation agencies to (a) collect and analyze safety and mobility data to manage the work zone impacts of individual projects during construction and (b) improve overall agency processes and procedures related to work zone safety and mobility. To help achieve these goals, the University of Maryland, in partnership with Maryland State Highway Administration (SHA) and FHWA, developed a Work Zone Performance Monitoring Application (WZPMA) that uses third party probe data for real-time monitoring and evaluation of work zones. The WZPMA was included as a tool within the Regional Integrated Transportation Information System (RITIS). This report provides an overview of the WZPMA as well as methodology used to compute various work zone performance measures. Example applications of the WZPMA are also provided.</td></tr>
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EXECUTIVE SUMMARY

In 2004 the Federal Highway Administration (FHWA) amended its regulation that governs traffic safety and mobility in highway work zones. The updated rule requires agencies to:

- Collect and analyze safety and mobility data to manage the work zone impacts of individual projects during construction; and

- Improve overall agency processes and procedures related to work zone safety and mobility.

In 2010 the Maryland State Highway Administration (SHA) and Federal Highway Administration (FHWA) jointly assessed SHA's Work Zone Safety and Mobility Program. FHWA's final report noted that SHA was not meeting the requirement of the aforementioned FHWA regulation in the area of work zone data collection. To help SHA meet these requirements, the University of Maryland developed a Work Zone Performance Monitoring Application (WZPMA) that uses third party probe data for real-time monitoring and evaluation of work zones. The WZPMA was developed in partnership with SHA and FHWA, and it is now included as a tool within the Regional Integrated Transportation Information System (RITIS).

The benefits of the developed WZPMA include:

- Assisting on-site monitoring of work zone impacts by providing real-time estimates of delays and queue lengths, information on incidents blocking travel lanes, and feedback on the effects of lane closures.

- Satisfying the requirements of the FHWA work zone regulation in the areas of work zone data collection and monitoring.

- Providing a cost-effective method of work zone data collection over fixed-sensor data collection at individual work zones statewide.

- Providing a programmatic means of evaluating work zone performance through the RITIS system, which enables both project-level and program-level evaluations.

This report provides an overview of the methodologies investigated to compute various performance measures shown in the WZPMA. It also includes an example application of work zone performance measures for a maintenance project along I-70. Lastly, the report provides a detailed overview of the WZPMA, including a user guide and screenshots of the final product. The WZPMA is a tool now available for use within RITIS. For access go www.ritis.org .

1. INTRODUCTION

On September 9, 2004, the Federal Highway Administration (FHWA) amended its regulation that governs traffic safety and mobility in highway and street work zones (23 CFR Part 630). The updated rule requires agencies to collect and analyze safety and mobility data to manage the work zone impacts of individual projects during construction and to improve overall agency processes and procedures related to work zone safety and mobility. During the summer of 2010, the Maryland State Highway Administration (SHA) and FHWA undertook a joint process assessment of SHA's Work Zone Safety and Mobility Program. FHWA's final report, which was issued in December 2010, noted that SHA is currently not meeting the requirement of the aforementioned FHWA regulation in the area of work zone data collection. The report recommended that SHA investigate new methods of collecting and documenting work zone crash and operational data. Additionally, the report recommended that SHA work with other offices within SHA, such as Office of CHART (Coordinated Highways Action Response Team) and ITS Development, to investigate new opportunities for data sharing, and work with the University of Maryland to research the potential use of real-time speed data from INRIX (INRIX, 2015) to improve State processes and procedures.

Under this project, the University of Maryland, in partnership with SHA and FHWA, developed a Work Zone Performance Monitoring Application (WZPMA) that was built upon research that examined the use of third party probe data for real-time monitoring and evaluation of work zones. This foundation research started in 2012 and resulted in:

1. Verification that third party probe data can be used to monitor real-time work zone performance and provide a basis for analyzing historical work zone performance;

2. Development of methodologies for calculating work zone performance measures and triggering real-time queue warning "Alerts";

3. Example output of performance measures based on existing work zones;

4. Development of a prototype graphical user interface "dashboard" for work zone performance measures; and

5. Gathering of SHA technical input on the prototype "dashboard".

The above findings of this research are also included in this report to help understand the methodologies behind WZPMA. The WZPMA was envisioned as a tool enabling users to quickly and easily monitor and assess real-time performance monitoring for work zones using data available through the Regional Integrated Transportation Information System (RITIS). The envisioned functionalities included:

- ***Assisting on-site construction project managers*** in monitoring work zone impacts by providing real-time estimates of delays and queue lengths monitoring, information on incidents blocking travel lanes, and feedback on the effects of lane closures. This information could be used by the Districts as a basis for modifying lane closure schedules or investigating high crash locations.

- ***Satisfying the requirements of the FHWA work zone regulation*** in the areas of work zone data collection and monitoring.

- ***Providing a cost-effective method of work zone data collection.*** The use of this tool would offer significant cost savings over fixed-sensor data collection at individual work zones statewide.

- ***Providing a programmatic means of evaluating work zone performance.*** The RITIS system would provide real-time work zone data for project level evaluations and offer the ability to query archived data for program level evaluations. The Office of Traffic and Safety would be able to use this tool in their bi-annual Work Zone Safety and Mobility Process Assessments.

- ***Developing a National Model*** for state transportation agencies seeking cost-effective, real-time monitoring of work zone impacts. The case study developed by FHWA and prototype tool would garner national attention, spotlight the work zone data collection and monitoring efforts at SHA and serve as a model for other state departments of transportation.

2. METHODOLOGY

This section first provides an overview of how work zone performance measures could be extracted from third party probe data and included in the development of the WZPMA. Second, a simple system is proposed to alert users about the build-up and propagation of congestion in the work zone based on the real-time speed data. Third, archived third party probe speed data dated back to May 2012 are analyzed and proposed measures are calculated for four work zones on I-70 westbound near Frederick, MD.

2.1. Work Zone Performance Measures

The performance measures overviewed in this subsection are primarily based on the guidelines published in a primer on the subject (Ullman, Lomax, & Scriba, 2011). The proposed measures are categorized into three different groups: Exposure, Safety, and Mobility. The exposure measures require volume and site related data, while safety measures are based on crash and incident data. Mobility related performance measures, the main focus of this project are primarily based on speed data, with additional information provided by volume data. Mobility measures are further divided into two subgroups: Delay and Queuing.

2.1.1. Delay

Delay is defined as the excess time a vehicle spends in the segment beyond what it would have spent under free flow conditions. To calculate delay (d_i) on a segment (i) , travel speed (V_i), reference speed $\left(V_{R,i}\right)$, and segment length (L_i) are needed. At any given time, delay (D) on a path composed of several Traffic Message Channel (TMC) segments can be simply calculated as the sum of delays (d_i) on each individual TMC segment during the same time period.

$$d_i = 60 * L_i * \left(\frac{1}{V_i} - \frac{1}{V_{R,i}}\right)$$

$$D = \sum d_i$$

2.1.2. Congestion

Congestion is defined as a situation where measured speeds (V_i) have fallen well below reference ($V_{R,i}$) and historic speeds ($V_{H,i}$) corresponding to the same segment and time period.

$$\begin{cases} congested, & if\ \left(V_i < \frac{\alpha}{100} * V_{R,i}\right)\ AND\ \left(V_i < V_{H,i}\right) \\ free - flow, & otherwise \end{cases}$$

Due to the nature of speed data and the research team's past experience, it is suggested that a higher factor ($\alpha = 80\%$) be used in defining whether a segment is congested or not. This is a more restrictive standard than what is currently being used in RITIS (α=60%).

Figure 1 illustrates Level of Service (LOS) definitions given by Highway Capacity Manual (HCM) for a basic freeway segment. Depending on free-flow speed, congestion sets in (LOS F) when speeds fall to the 50 mph level and below.

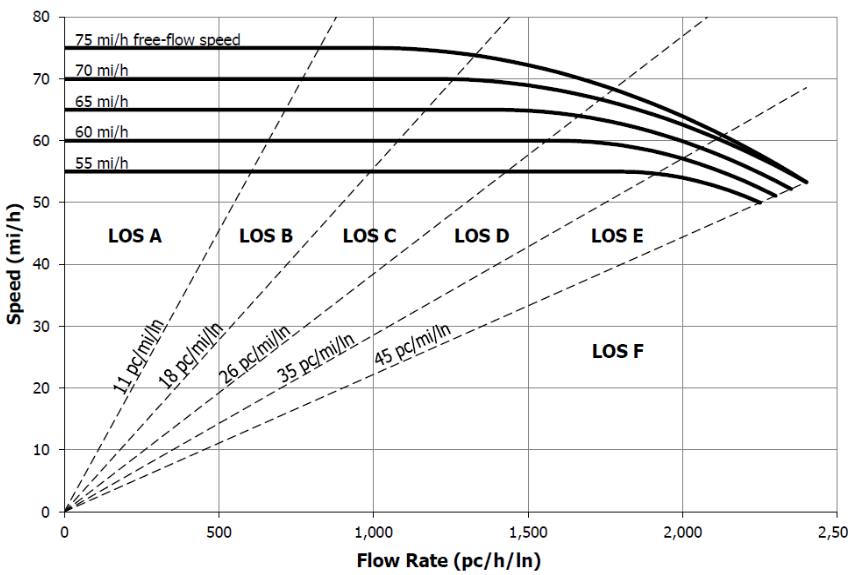


Figure 1: Level of service definitions for a basic freeway segment (Source: HCM 2010)

It should be noted that 50 mph is about 67% and 91% of the freeway free flow speeds of 75 mph and 55 mph, respectively ($\gamma < 0.67{\sim}0.91$) (see the following paragraph for definition). The HCM definition assumes a homogeneous and uniform operation throughout the segment. In this application, however, it is desirable to define that a segment is congested even when it is only partially congested. Assume a segment with length L is operating with speed V under both uncongested (length L_1, free flow speed $v_1 = v_f$) and congested (length L_2, speed $v_2 < v_f$) modes. Then average speed is:

$$V = \frac{L}{\frac{L_1}{v_f} + \frac{L_2}{v_2}}$$

Substituting L_1 with $L - L_2$ in the above equation, dividing both sides by free flow speed $\left(v_f\right)$ and factoring out segment free flow travel time $\left(\frac{L}{v_f}\right)$

$$\frac{V}{v_f} = \frac{1}{1 - \frac{L_2}{L} + \frac{\frac{L_2}{L}}{\frac{v_2}{v_f}}}$$

To further simplify the presentation of results, above equation can be re-written as

$$\alpha = \frac{1}{1 - \beta + \frac{\beta}{\gamma}}$$

where,

$\alpha = \frac{V}{v_f}$, is the ratio of segment speed to free flow speed

$\beta = \frac{L_2}{L}$, is the ratio of segment length which is congested, and

$\gamma = \frac{v_2}{v_f}$, is the ratio of speed to free flow speed at congested part of segment.

Figure 2 exhibits variations of α with respect to β and γ when each varies between zero and one. It should be noted when more than half of the segment length is congested ($\beta > 0.5$) and speed levels at the congested portion are at the border of LOS F ($\gamma < 0.67 \sim 0.91$) then ratio of segment speed to free flow speed has to be less than 80% ($\alpha < 0.8$).

To summarize the analysis, the chosen cut-off point for flagging a segment as congested ($\alpha < 0.8$) is based on the following two main criteria:

1. The congested portion of the subject segment is longer than half of the segment length; and

2. The congestion levels at congested parts of the segment must be high (LOS F or ($\gamma < 0.67 \sim 0.91$)).

2.1.3. Queue Length

Queue formation in road segments is directly related to the concept of congestion. It is assumed that when and where congestion exists, queues also take form. Figure 2 illustrates that when segment speed falls to 90, 80, and 70 percent of its reference speed ($\alpha = 0.9, 0.8, 0.7$), then at least 23, 50, and 87 percent of the segment length will be densely congested ($\gamma < 0.67$), respectively. In fact, algebraic manipulation of the last equation obtained in previous section would reveal the following relationship

$$\beta = \frac{\frac{1}{\alpha} - 1}{\frac{1}{\gamma} - 1}$$

when set at $\gamma = 0.67$ would result in the following inverse relationship between the minimum length of the congested portion of the segment (β_{min}) and the speed ratio ($0 \leq \alpha \leq 1$),

$$\beta_{min} = Min\left\{2.03 * \left(\frac{1}{\alpha} - 1\right), 1\right\}$$

Figure 3 is a graphic illustration of the above relationship. It should be noted that when speed ratio is less than 67 percent the segment is assumed to be fully congested and the queue length is equal to the full length of the segment. Increasing speed ratio would result in decreasing minimum segment queue length from one to zero as the speed approaches the free flow speed ($\alpha = 1$). Therefore, once the speed ratio of a TMC segment is known, the queue length (ql) can be estimated as a fraction of the segment full length (L)

$$ql = \beta_{min} * L$$

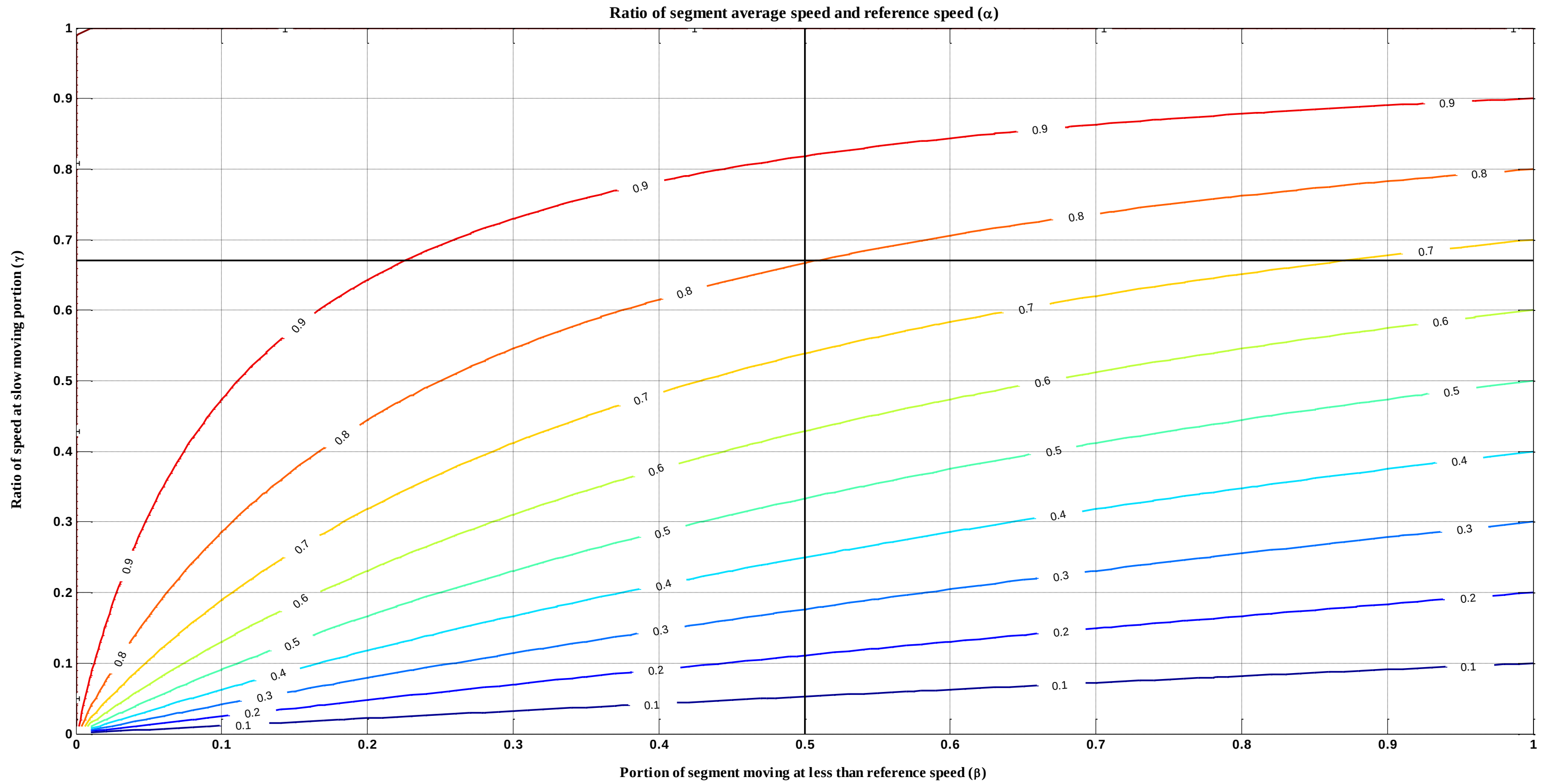


Figure 2: Segment speed variations with respect to length and speed of congested portions of the segment.

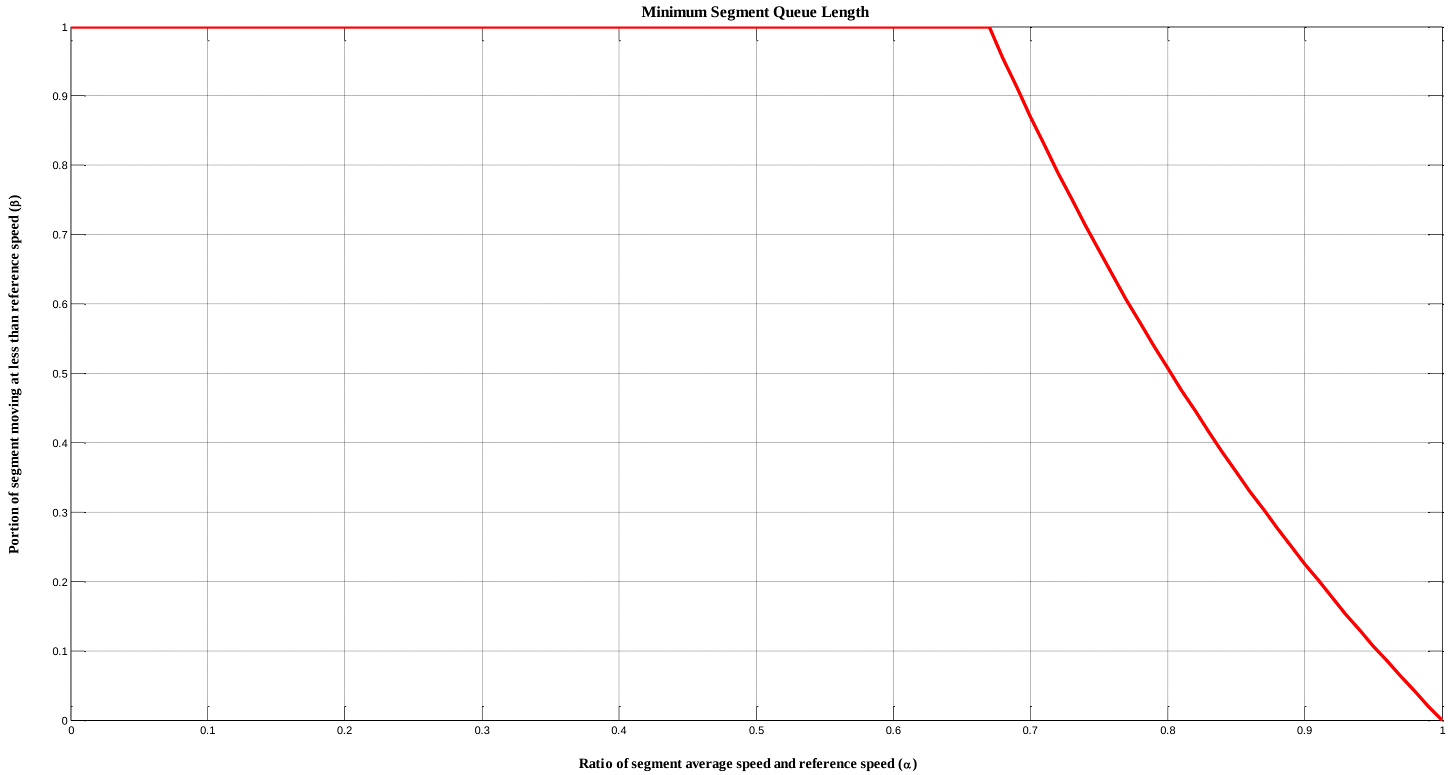


Figure 3: Minimum segment queue length as a function of the ratio of segment speed and reference speed

Table 1 summarizes the above measures. It should be noted that these measures are defined for each TMC segment in the work zone area.

Table 1: Mobility related performance measures of work zones

Measure	Unit	Equation	Notes
Delay	Min	$d_i = 60 * L_i * \left(\frac{1}{V_i'} - \frac{1}{V_{R,i}}\right)$ $V_i' = Min(V_i, V_{R,i})$ $D = \sum d_i$	Speed used to calculate the delay on the segment is the minimum of reported average and reference speeds.
Congestion	Binary	$C_i = \begin{cases} 1, & V_i < Min\left(\alpha * V_{R,i}, V_{H,i}\right) \\ 0, & otherwise \end{cases}$	Congestion is assumed to set in when speed goes below BOTH 80% of reference speed (α=0.8) AND historic average speed
Queue Length	Miles	$(ql)_i = \beta_{i,min} * L_i$ $\beta_{i,min} = Min\left\{2.03 * \left(\frac{V_{R,i}}{V_i'} - 1\right), 1\right\}$ $V_i' = Min(V_i, V_{R,i})$	Queue length is assumed to be a fraction of segment length varying between 0 and 100 percent. Speed used to calculate the queued fraction of segment length is the minimum of reported and reference speeds.

2.1.4. Path segments

To build these measures for a path comprised of several individual segments it is possible to estimate path travel speed (V_p), path average historic speed $(V_{H,p})$, and path reference speed $(V_{R,p})$ using the following weighted harmonic average formula

$$V_p = \frac{\sum_i L_i}{\sum_i \left(\frac{L_i}{V_i}\right)}$$

$$V_{R,p} = \frac{\sum_i L_i}{\sum_i \left(\frac{L_i}{V_{R,i}}\right)}$$

$$V_{H,p} = \frac{\sum_i L_i}{\sum_i \left(\frac{L_i}{V_{H,i}}\right)}$$

In this application a work zone is divided into three identifiable segments: Upstream, Work area, and Downstream. Upstream and downstream segments should be long enough to capture shockwaves moving towards or away from the work area within the update period. For instance, in case of one minute speed updates on a facility with a 65 mph reference speed, the upstream and downstream segments must be at least 65/60=1.1 mile long. This arrangement will make it possible to actually detect the source of congestion and trace its propagation into and out of the study area both in spatial and temporal terms.

It can be shown that using path speeds will produce the same results in estimating delay as computing delays for each segment separately and then adding them up

$$D = 60 * \left[\sum_i L_i\right] * \left(\frac{1}{V'_p} - \frac{1}{V_{R,p}}\right) = \sum d_i = 60 * \sum_i \left[L_i * \left(\frac{1}{V'_i} - \frac{1}{V_{R,i}}\right)\right]$$

where,

$$V'_p = Min(V_p, V_{R,p})$$

However, calculating the congestion and queue length measures for a path segment comprised of multiple TMC segments requires paying special attention to existing conditions in each TMC segment and interactions among neighboring TMC segments.

Congestion in a path segment can be simply estimated using a technique analogous to the single TMC segments

$$C_p = \begin{cases} 1, & V_p < Min\left(\alpha * V_{R,p}, V_{H,p}\right) \\ 0, & otherwise \end{cases}$$

However, in this application location and propagation of the congestion in the upstream and downstream segments are as important. For instance, it would be critical to know whether congestion on the upstream path segment is propagating towards or away from the work area. The first case would mean congestion from upstream sources is moving toward the work zone, while the second case would indicate that work zone bottleneck is activated (either due to work zone related road closures or moving bottlenecks initiated downstream from the work area) and resulting congestion is propagating back toward upstream locations.

To further the congestion monitoring capabilities, it is suggested that the extent between and including the last two congested TMC segments (from either direction) in the path segment be reported. Additionally, the distance from the relevant end of work area to the beginning of the first congested TMC segment in the path segment is reported. Monitoring these measures over time will inform the extent of congestion as well as the proximity and direction in which congestion is moving relative to the work area of interest.

In calculating queue length in a path segment the fact should be taken into account that queues in consecutive TMC segments may be intermittent. Then the question that needs to be addressed is that what minimum distance between two dense queues would warrant calling them separate from each other. Answering this question first requires knowing where queues are located (start and end) inside each TMC segment. Based on space mean speed data alone this level of detail is difficult to achieve. But, in the worst case, it can be assumed that free-flow portions of two neighboring TMC segments are adjacent to each other which would result in maximum length of separation between their respective queues. Then, assuming at least 5 seconds of travel time at reference (free flow) speed between the two queues would warrant calling them as separate one can write

$$\left[(1-\beta_{i,min})\frac{L_i}{V_{R,i}}+(1-\beta_{i+1,min})\frac{L_{i+1}}{V_{R,i+1}}\right]*3600\ sec/hr \leq 5\ sec$$

when segments are numbered in the traffic direction. In freeway facilities (free flow speed nearly 60mph) this can be approximated as

$$(1-\beta_{i,min})L_i+(1-\beta_{i+1,min})L_{i+1} \leq 0.083\ mile\ (\cong 440ft)$$

$$A_{i+1}=\begin{cases}1, & (1-\beta_{i,min})L_i+(1-\beta_{i+1,min})L_{i+1} \leq 0.083\\ 0, & otherwise\end{cases}$$

$$A_1=0$$

Moving downstream from the first TMC segment, the chain of consecutive TMC segments will be broken into sub chains based on where the next TMC segment with $A_i=0$ is located. Then, the maximum queue length on the path segment of interest can be calculated as

$$QL=Max_k\left(\sum\nolimits_{i\in C_k}(ql)_i\right)$$

the first two mobility related performance measures (delay and congestion) for each of the three principal segments.

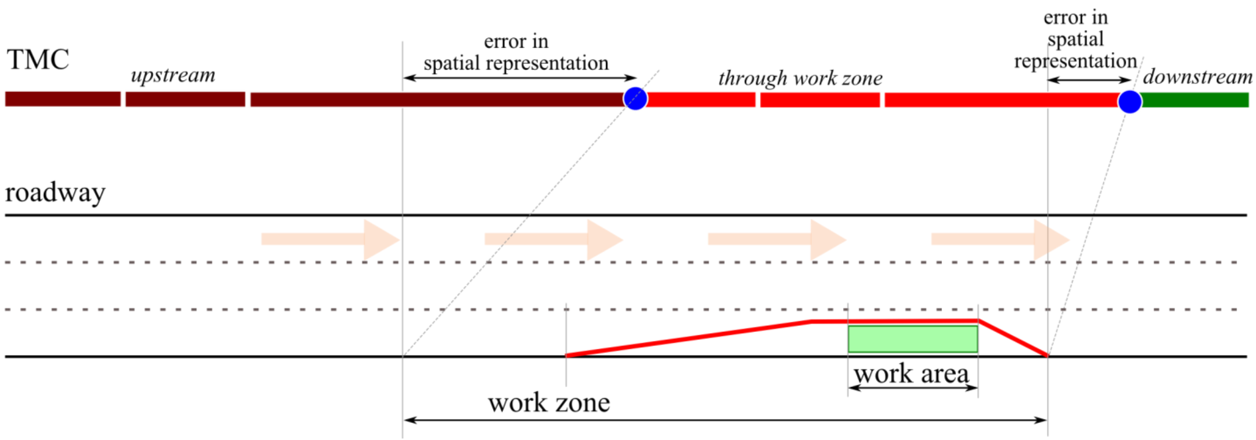


Figure 4: Typical work zone and its three identifiable segments

In case TMC segments do not line up exactly with boundaries of the work zone segments it is recommended that appropriate TMC segments to be broken into two or more segments as necessary. The resulting sub TMC segments will inherit the same average, reference and historic speeds as the original TMC segment. The reported travel time for the original TMC segment, however, should be broken down into its corresponding parts proportionally to account for the length of each sub TMC segment. Figure 4 exhibits an example of such a situation where tapered tails of the road closure start and end in the middle of the associated TMC segments.

2.1.5. Programmatic performance measures

Table 2 lists a number of mobility related performance measures that can be built on top of basic measures discussed earlier. Some of these PMs require volume data which is not readily available at this point.

Table 2: Work zone mobility performance measures

Work Zone Mobility PMs (Traffic Operations)	Data requirement		Included in WZMPA?
	speed	volume	
Number or % of days or work activity periods when queuing occurred	✓		Y
Average queue duration	✓		Y
Average queue length	✓		Y
Maximum queue length	✓		Y
% Time when work zone queue length exceeds XX miles	✓		Y
Amount (or % of ADT) that encounters a queue	✓	✓	N
Vehicle-hours of delay per: • Work period • Work period when queues are present • Peak period • Project	✓	✓	Y
Average delay per: • Entering vehicle • Queued vehicle • Peak period vehicle	✓	✓	Y
Maximum per-vehicle delay	✓	✓	Y
Number (or % of ADT) Vehicles experiencing delays greater than XX minutes	✓	✓	N

2.2. Alert System

In developing the WZPMA, it was indicated that it would be desirable to use available speed data in order to develop a simple alert system. The purpose of the alert system is to indicate when congestion is set off and propagating upstream in the system. The system can be potentially used to make operational and/or planning decisions as well as help monitor the effectiveness and impacts of various possible counter-measures in real-time.

The proposed alert system is based on the following observations. A work zone bottleneck is activated when the work area gets congested and then congestion propagates upstream. It may be argued that other cases, where shockwaves resulting from downstream congestion travels through work area and later into upstream do not warrant an alert, nevertheless, eminent existence of congestion upstream and inside work area can be viewed as hazardous conditions to workers, drivers, and traffic operations in general. Therefore, in its current form, the system issues an alert anytime congested situation in the work area or upstream is detected. Currently, the following rule is used to decide whether an alert should be issued or not: if work area is congested OR upstream segment is congested THEN issue an alert.

2.3. Sample Application: I-70

In this section, mobility performance measures for a work zone in Maryland are reported using third party probe data. The work zone included in this analysis is located on Westbound I-70, East of Frederick @ South St./Exit 55 (Project Description, 2012). Table 3 presents further details on planned lane closures which are obtained from a list of incidents archived in RITIS. In addition, lists of other incidents in the impact area of the studied work zones are queried and obtained from RITIS. In the following sections, based on the timeline of events in each case, the analysis results are interpreted. In the first case (Westbound on I-70), sample calculations are presented to better illustrate how real-time speed data can be used to calculate the proposed performance measures. Also, in each case, the amount of data that goes into generating graphs and associated performance measures are reported.

Table 3: Work zone locations, their associated lane closures, and timelines

Highway		I-70	Highway		I-70
Direction		Westbound	Direction		Westbound
WZ 1	Location	B/W Exit 62 MD 75 Green Valley Rd and Linganor	WZ 3	Location	At E South St
	Lane Closure	R Shoulder		Lane Closure	R Shoulder + (1) R Lane
	Start time	5/8/12 8:20am		Start time	5/8/12 8:08pm
	End time	5/8/12 2:54pm		End time	5/9/12 12:13am
	Duration	6 hours 34 minutes		Duration	4 hours 4 minutes
WZ 2	Location	B/W MP 63 and MP 61	WZ 4	Location	B/W Exit 62 MD 75 Green Valley Rd and Linganor
	Lane Closure	L Shoulder + (1) L Lane		Lane Closure	R Shoulder
	Start time	5/8/12 9:21am		Start time	5/9/12 9:50am
	End time	5/8/12 1:56pm		End time	5/9/12 3:23pm
	Duration	4 hours 34 minutes		Duration	5 hours 33 minutes

This work zone is modeled using a set of eleven TMC segments as listed in Table 4. Upstream, work area, and downstream segments in each identified work zone is reported as the portion of each TMC segment belonging to these parts. The upstream, work area and downstream lengths in each case are reported in Tables 5, 6, and 7, respectively.

Figure 5 illustrates the general location of the work zone on westbound I-70, east of Frederick and just to the south of Frederick municipal airport. In Figure 5 segment from A to B is upstream, segment from B to C is the work area, and the segment from C to D is the downstream.

In the following pages, separate graphs are provided to illustrate speed variation in more interesting times during May 2012. Graphs for speed, delay, and queue length variations are provided. Alerts are also imposed on speed and delay graphs to provide an opportunity for closer study of the proposed system's performance.

Table 4: TMC Characteristics on Westbound I-70

tmc	intersection	zip	start_latitude	start_longitude	end_latitude	end_longitude	miles
110+04489	Carroll/Howard County Line (Mount Airy) (East)	21771	39.344732	-77.077416	39.357122	-77.1392	3.45
110+04677	MD-27/Exit 68	21771	39.357122	-77.1392	39.36045	-77.158395	1.13
110P04195	MD-27 (Retired)	21771	39.36045	-77.158395	39.359121	-77.170049	0.63
110+04196	MD-75/Exit 62	21770	39.359121	-77.170049	39.380484	-77.25356	4.85
110P04196	MD-75/Exit 62	21770	39.380484	-77.25356	39.381657	-77.266745	0.72
110+04197	MD-144/Exit 59	21701	39.381657	-77.266745	39.3934318	-77.3259404	3.33
110P04197	MD-144/Exit 59	21701	39.3934318	-77.3259404	39.393696	-77.326293	0.03
110+04198	MD-144/Exit 56	21701	39.393696	-77.326293	39.404465	-77.384016	3.35
110+04199	South St/Exit 55	21704	39.404465	-77.384016	39.404766	-77.388921	0.26
110P04199	South St/Exit 55	21704	39.404766	-77.388921	39.4043446	-77.3924646	0.19
110+04200	MD-355/Exit 54	21703	39.4043446	-77.3924646	39.400225	-77.408674	0.91
TOTAL							18.86

Table 5: TMC lengths involved in upstream portion of each work zone on Westbound I-70

tmc	WZ1	WZ2	WZ3	WZ4
110+04489	3.45	3.45	3.45	3.45
110+04677	1.13	1.13	1.13	1.13
110P04195	0.63	0.63	0.63	0.63
110+04196	4.85	4.15	4.85	4.85
110P04196	0.60	0	0.72	0.60
110+04197	0	0	3.33	0
110P04197	0	0	0.03	0
110+04198	0	0	3.35	0
110+04199	0	0	0.26	0
110P04199	0	0	0.09	0
110+04200	0	0	0	0
TOTAL	10.66	9.36	17.85	10.66

Table 6: TMC lengths involved in work area portion of each work zone on Westbound I-70

tmc	WZ1	WZ2	WZ3	WZ4
110+04489	0	0	0	0
110+04677	0	0	0	0
110P04195	0	0	0	0
110+04196	0	0.70	0	0
110P04196	0.12	0.72	0	0.12
110+04197	3.33	0.70	0	3.33
110P04197	0.03	0	0	0.03
110+04198	2.15	0	0	2.15
110+04199	0	0	0	0
110P04199	0	0	0.10	0
110+04200	0	0	0.10	0
TOTAL	5.63	2.12	0.20	5.63

Table 7: TMC lengths involved in downstream portion of each work zone on Westbound I-70

tmc	WZ1	WZ2	WZ3	WZ4
110+04489	0	0	0	0
110+04677	0	0	0	0
110P04195	0	0	0	0
110+04196	0	0	0	0
110P04196	0	0	0	0
110+04197	0	2.63	0	0
110P04197	0	0.03	0	0
110+04198	1.20	3.35	0	1.20
110+04199	0.26	0.26	0	0.26
110P04199	0.19	0.19	0	0.19
110+04200	0.91	0.91	0.81	0.91
TOTAL	2.57	7.38	0.81	2.57

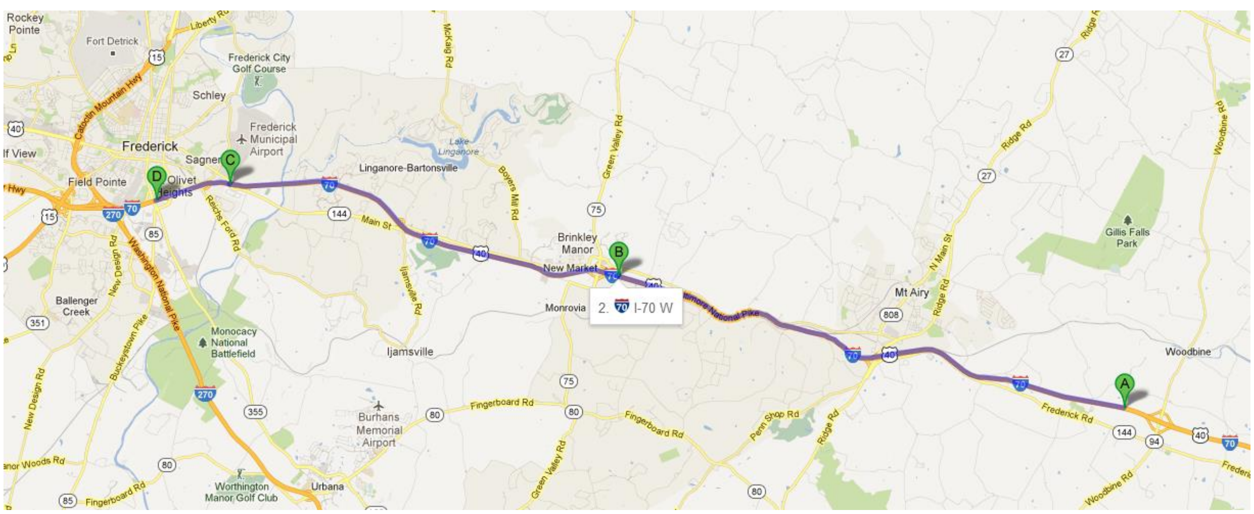


Figure 5: General map of the first identified work zone location on westbound I-70

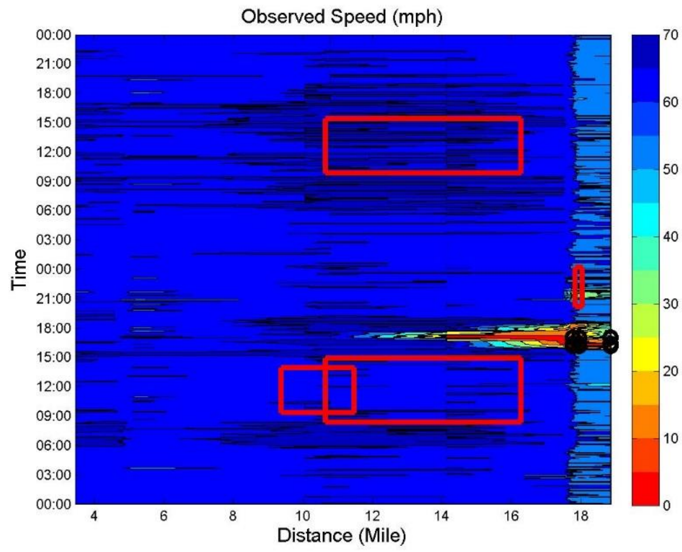


Figure 6: Speed heat map on westbound I-70 segments on May 8-9, 2012.

Figure 6 exhibits the observed speeds on more than 18 miles long stretch of westbound I-70 that is being studied. The speed data reported here is from May 8-9, 2012. In Figure 6, slow speeds are depicted using red colors while higher speeds are depicted as bluish colors. The association of colors with speeds is shown in the color bar next to the heat map. Figure 6 illustrates that in general, with the exception of a major slow-down just after 3:00 pm on May 8th and a minor slow-down later that night around 9:00 pm, the vehicles on the studied segment operate at a high speed. However, the effect of getting closer to the city limits and corresponding reduction in speeds is obvious from lighter blue colors that start at about 18 mile point and which stay that way throughout the two days of study.

Table 8: Relevant incidents log on westbound I-70 reported during May 8-9, 2012

Type	Location	Latitude	Longitude	Time Opened	Time Closed	Duration	Max Lanes Closed
Road Maintenance Operations	I-70 BETWEEN EXIT 62 MD 75 GREEN VALLEY RD & LINGANORE RD	39.381888	-77.260056	8:20	14:54	6:34	1
Road Maintenance Operations	I-70 BETWEEN MP 63 & MP 61	39.378919	-77.247656	9:21	13:56	4:34	2
Collision	I-70 AT EXIT 55 E	39.403872	-77.393592	15:45	16:46	1:01	

	SOUTH ST						
Obstructions	I-70 AT MD 355	39.399935	-77.40927	16:03	16:48	0:44	
Congestion	I-70 AT MUSSETTER RD	39.38596	-77.298129	17:18	17:54	0:35	
Road Maintenance Operations	I-70 AT E SOUTH ST	39.403928	-77.393654	20:08	5/9/12 0:13	4:04	2

In Figure 6, four red rectangles correspond to the zone activities on westbound I-70 that are identified in Table 3. The black circles in Figure 6 are meant to highlight spots where road closures are reported in speed data (speed equal to zero and travel time equal to -1). Further investigation showed that for 19 minutes speeds at the last three TMC segments reported a complete roadway shut-down which seems to be the root cause of the major congestion illustrated in Figure 6. Then, the corresponding incident logs in Table 8 confirmed this roadway closure. Apparently, at 15:45 pm on May 8 a collision is reported at westbound I-70 at Exit 55 E South St. involving a dump truck going wrong way on lane 2. Based on the records, this incident (and its impact) lasted for one hour and one minute. The recorded operator notes (Table 9) indicate that the construction company shut down the ramp from Monocacy Blvd to westbound I-70 in order to send a heavy tow truck in the wrong way on westbound I-70 to clear the scene of collision.

Table 9: Notes on "Collision" incident on I-70 West at Exit 55 E South St.

Timestamp	Username	Message
16:09	bmurphy	DUMP TRUCK FACING WRONG WAY IN LN 2.
16:32	bmurphy	9703-CONSTRUCTION COMPANY ON MON. BLVD WILL SHUT DOWN RAMP FROM MON. TO WB I 70 SO HEAVY TOW CAN GO WRONG WAY ON WB 70 IN ORDER TO CLEAR THE SCENE

The following sections summarize the analysis and findings related to each work zone identified on the study segment during the two day time period (May 8-9, 2012). The analysis results in measures for delay, congestion, and queue length on each portion of the work zones. Performance measures computed using the results in each case are also reported.

2.3.1. I-70 West b/w Exit 62 (MD-75 Green Valley Road) and Linganore Road

Table 10 shows performance measures computed based on speed data in the area of study. The reported performance measures are broken down to measures on each portion of the work zone during the work zone operations (6 hours and 34 minutes = 394 minutes).

Table 10: Performance measures for WZ1 on westbound I-70.

Performance Measure	Unit	Upstream	Work Area	Downstream
Length	Mile	10.66	5.63	2.57
Average Delay	Minute	0.03	0.03	0.16
Maximum Delay	Minute	0.24	1.32	1.14
Queue Duration	Minute	330	135	394
Average Queue Length	Mile	0.06	0.06	0.34

Maximum Queue Length	Mile	0.52	2.15	2.04
Percent Time Queue Length Exceeds 1 miles	%	0.00	0.25	2.03

Figure 7 depicts the observed travel speed variations on each portion of the work zone. The blue color represents speeds at upstream of the work zone, while speeds at the work area are represented by red colored lines. The green lines represent downstream speeds. Also, in Figure 7, the real time speeds are depicted using solid lines while dotted lines represent historic speeds. The two vertical black lines identify the start time and end time of the work zone. The general trends and differences between speeds at upstream, work area, and downstream segments follow the expected trend where speeds generally fall when approaching urban areas.

In this case only the right shoulder of the highway is closed. As seen in Figure 7, the impact of the work zone on traffic speeds is minimal except for a short hiccup after 12:00 noon. That congestion seems to propagate upstream into the work area since the dip in speed is first detected at a downstream location. The other notable observation in Figure 7 is that after the end of work zone a severe slow-down starts downstream just before 16:00 pm. First, it was thought that this is due to recurring congestion during the PM peak period, but further investigation conducted based on the speed heat map of the area and digging into incidents logs revealed that this major dip in speeds is brought about due to a severe accident that happened downstream and led to a total shut down of highway for about 20 minutes. For further details on this incident and its impact please see the earlier discussion on speed heat map shown in Figure 6.

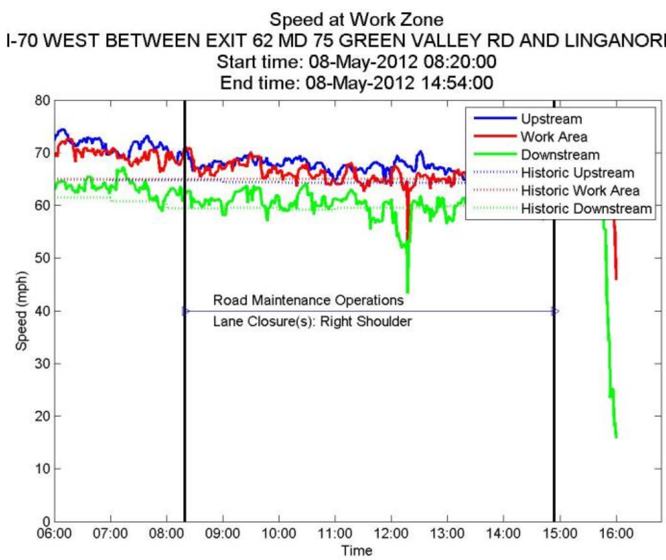


Figure 7: Speeds for WZ1 on westbound I-70.

Figure 8 shows delays experienced by drivers along each portion of the work zone under study. Again, the color coding is similar to what is used in Figure 7. Delays on all parts of the subject work zone are shown to be negligible with an exception right after midday (12:00 noon) when delays downstream and inside work area rise to the one minute level. The next significant increase in delay happens after the work zone is closed just before 15:00 pm.

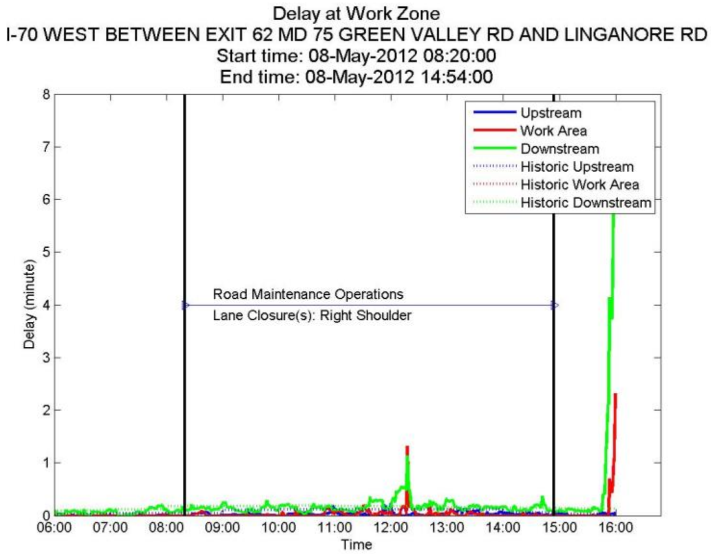


Figure 8: Delays for WZ1 on westbound I-70.

Figure 9 shows queue lengths formed on each portion of the work zone under study. The color coding is similar to what is used in Figure 7. In this Figure, queue lengths are additive. This means that reported queue lengths are the summation of queue lengths in each TMC segment. Figure 7 suggests that half a mile queue lengths in the downstream segment are very common while queues that form inside the work area and in the upstream segment are generally shorter. The major spike in queue length happens just after noon time which is consistent with speed and delay observations in previous Figures. The additive queue lengths downstream and in the work area reach two miles long which is significant given the 5.63 mile and 2.57 mile length of those segments, respectively.

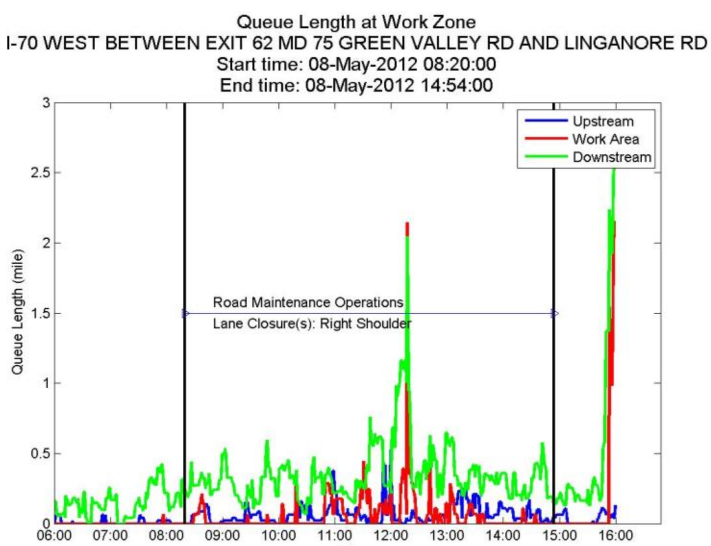


Figure 9: Queue lengths for WZ1 on westbound I-70.

Figure 10 shows the length of connected queues formed (according to the criteria defined in the methodology section) on each portion of the work zone under study. The color coding is similar to previous Figures. Figure 10 suggests that connected queue length is a more stable measure of traffic queue lengths in comparison with the simple additive queue lengths measure. In fact, imposing the connectivity criteria leads to a general decrease in the frequency by which a queue is reported. At the same time, it keeps the major queues intact and reports them without a significant loss in their estimated lengths. Again, the longest queues during the work zone operation period are reported downstream and inside the work area while connected queues forming in the upstream region are shorter but more frequent.

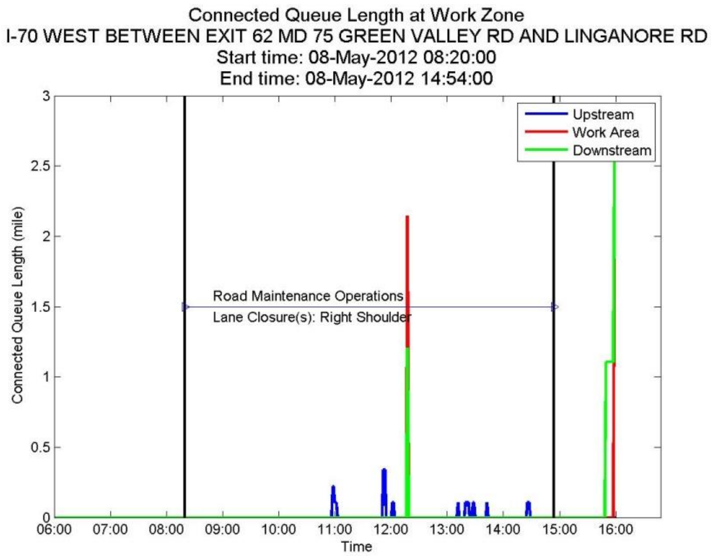


Figure 10: Connected queue lengths for WZ1 on westbound I-70.

Figure 11 exhibits the congestion flags and corresponding alert message in the first investigated work zone (WZ1) identified in the westbound I-70 corridor. Figure 11 shows that during work zone operation time congestion is only detected once in the downstream segment just after noon (12:00 pm) which can probably be associated with a sudden increase in local lunch time travel, but it does not trigger any alarms since the congestion does not propagate upstream into the work area. However, after the work zone closes right before PM rush hour (around 15:00 pm), congestion in the downstream segment is detected (before 16:00 pm) which later leads to congestion inside the work area and promptly results in issuing an alert. However, since the alert happens after the work zone operations end it has to be taken only as a test on the sensitivity and accuracy of the alert system.

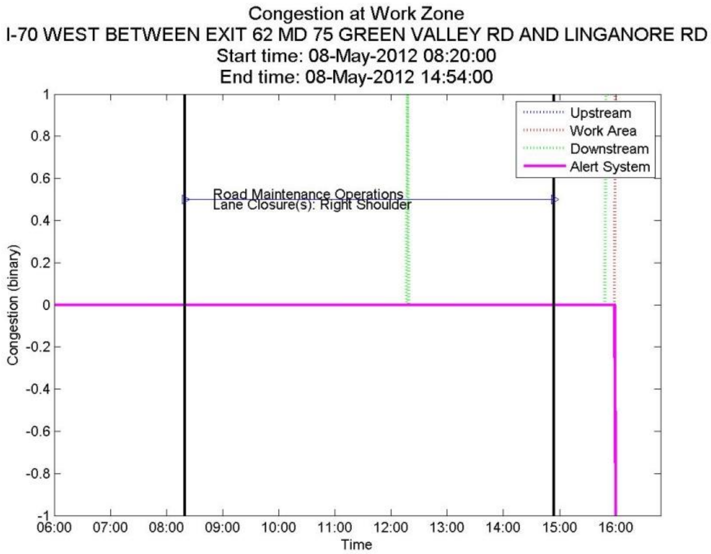


Figure 11: Congestion and alerts for WZ1 on westbound I-70.

2.3.2. I-70 West B/W MP 63 and MP 61

Table 11 shows performance measures computed based on speed data in the area of study. The reported performance measures are broken down to measures on each portion of the work zone during the work zone operations (4 hours and 34 minutes = 274 minutes).

Table 11: Performance measures for WZ2 on westbound I-70.

Performance Measure	Unit	Upstream	Work Area	Downstream
Length	Mile	9.36	2.12	7.38
Average Delay	Minute	0.03	0.00	0.21
Maximum Delay	Minute	0.19	0.13	2.46
Queue Duration	Minute	236	51	275
Average Queue Length	Mile	0.07	0.01	0.43
Maximum Queue Length	Mile	0.41	0.29	4.19
Percent Time Queue Length Exceeds 1 miles	%	0.00	0.00	4.36

Figure 12 depicts the observed travel speed variations on each portion of the work zone. The blue color represents speeds upstream of the work zone, while speeds in the work area are represented by red colored lines. The green lines represent downstream speeds. Also, in Figure 12, the real time speeds are depicted using solid lines while dotted lines represent historic speeds. The two vertical black lines identify the start time and end time of the work zone. The general trends and differences between speeds at the upstream, work area, and downstream segments follow the expected trend where speeds generally fall when approaching urban areas.

In this case, the left shoulder and one left lane of the highway are closed. As seen in Figure 12, the impact of work zone on traffic speeds is minimal except for a short hiccup after 12:00 noon.

That congestion seems to be restrained inside the downstream portion and does not propagate upstream into the work area.

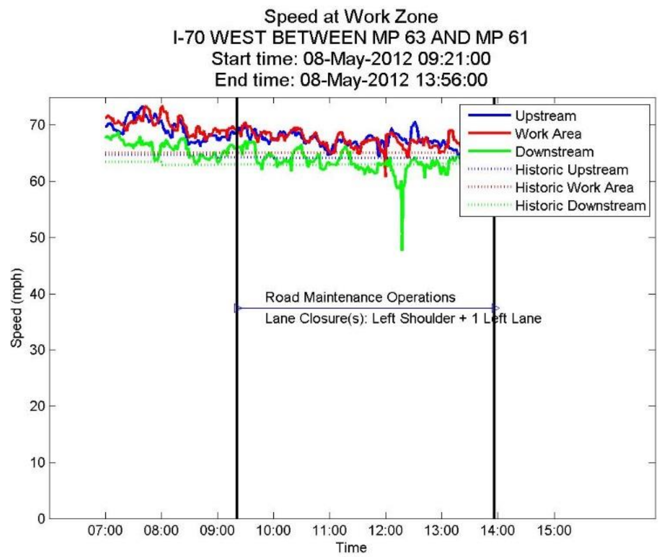


Figure 12: Speeds for WZ2 on westbound I-70.

Figure 13 shows delays experienced by drivers along each portion of the work zone under study. Again, the color coding is similar to what is used in Figure 7. Delays at all parts of the subject work zone are shown to be negligible with an exception right after midday (12:00 noon) when delays at downstream rise to the two and half minute level.

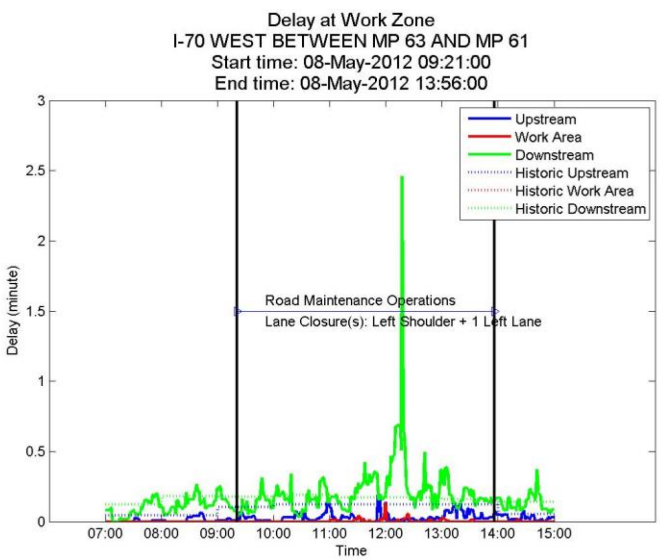


Figure 13: Delays for WZ2 on westbound I-70.

Figure 14 shows queue lengths formed on each portion of the work zone under study. The color coding is similar to what is used in Figure 7. In this Figure, queue lengths are additive. This means that reported queue lengths are the summation of queue lengths in each TMC segment. Figure 14 suggests that half a mile queue lengths in the downstream segment are very common while queues that form inside the work area and upstream are generally shorter. The major spike in queue length happens just after noon time which is consistent with speed and delay observations in previous Figures. The additive queue lengths in the downstream segment reach four miles long which is significant given the 7.38 mile length of the downstream segment in this case.

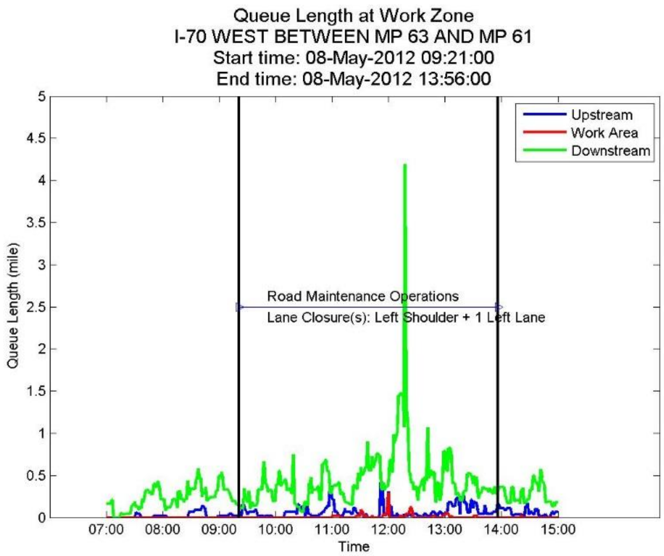


Figure 14: Queue lengths for WZ2 on westbound I-70.

Figure 15 shows the length of connected queues formed (according to the criteria defined in the methodology section) on each portion of the work zone under study. The color coding is similar to previous Figures. Figure 15 suggests that connected queue length is a more stable measure of traffic queue lengths in comparison with the simple additive queue lengths measure. In fact, imposing the connectivity criteria leads to a general decrease in the frequency by which a queue is reported. At the same time, it keeps the major queues intact and reports them without a significant loss in their estimated lengths. Again, the longest queues during the work zone operation period are reported downstream while connected queues forming in the upstream region are shorter but more frequent.

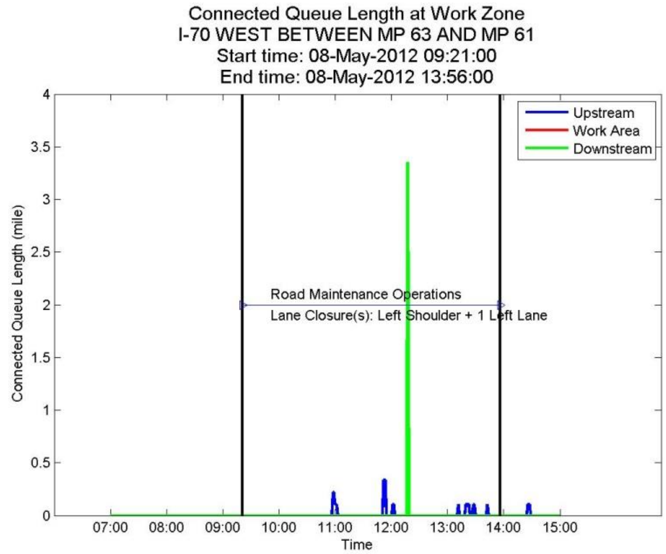


Figure 15: Connected queue lengths for WZ2 on westbound I-70.

Figure 16 exhibits the congestion flags and corresponding alert messages (if any) in the second investigated work zone (WZ2) identified in the westbound I-70 corridor. Figure 16 shows that during the work zone operation time congestion only has been detected once in downstream segments just after noon (12:00 pm) which can probably be associated with a sudden increase in local lunch time travel, but it does not trigger any alarms since the congestion does not propagate upstream into the work area.

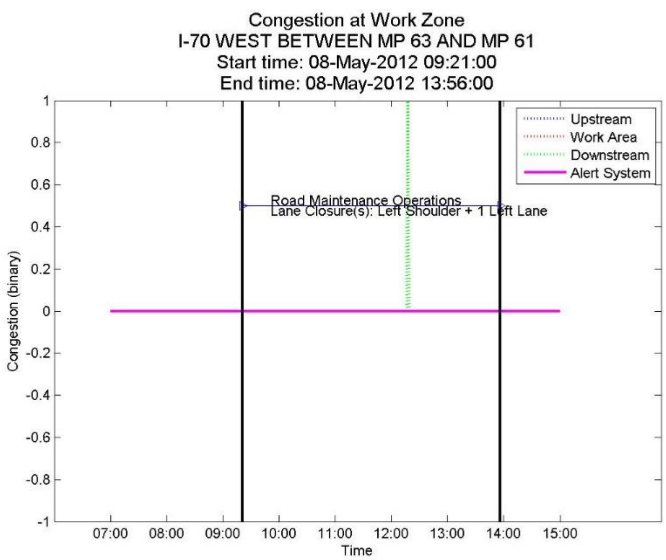


Figure 16: Congestion and alerts for WZ2 on westbound I-70.

2.3.3. I-70 West at East South Street

Table 13 shows performance measures computed based on speed data in the area of study. The reported performance measures are broken down to measures on each portion of the work zone during the work zone operations (4 hours and 4 minutes = 244 minutes).

Table 12: Performance measures for WZ3 on westbound I-70.

Performance Measure	Unit	Upstream	Work Area	Downstream
Length	Mile	17.85	0.20	0.81
Average Delay	Minute	0.27	0.04	0.14
Maximum Delay	Minute	1.09	0.17	0.50
Queue Duration	Minute	245	230	228
Average Queue Length	Mile	0.55	0.07	0.28
Maximum Queue Length	Mile	2.07	0.20	0.81
Percent Time Queue Length Exceeds 1 miles	%	22.04	0.00	0.00

Figure 17 depicts the observed travel speed variations on each portion of the work zone. The blue color represents speeds upstream of the work zone, while speeds at the work area are represented by red colored lines. The green lines represent downstream speeds. Also, in Figure 17 the real time speeds are depicted using solid lines while dotted lines represent historic speeds. The two vertical black lines identify the start time and end time of the work zone. The general trends and differences between speeds at the upstream, work area, and downstream segments follow the expected trend where speeds generally fall when approaching urban areas.

In this case the right shoulder and one right lane of the highway are closed. As seen in Figure 17, the impact of work zone on traffic speeds is significant almost throughout the work zone activity from 8:00 pm until past midnight. The congestion seems to propagate downstream outside the work area since the dip in speed is first detected inside the work area.

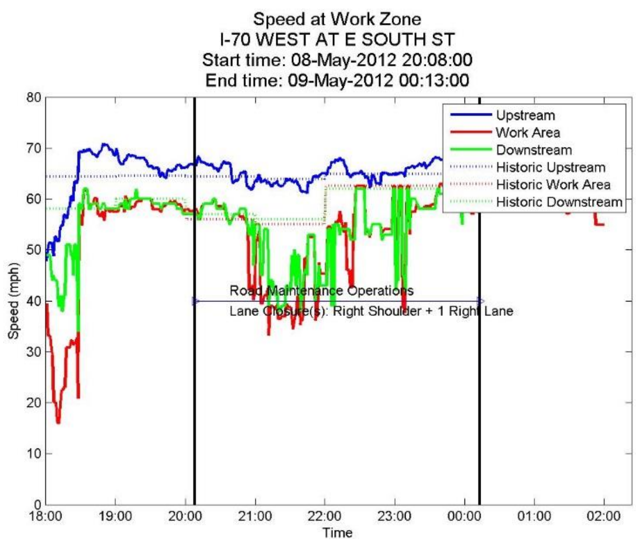


Figure 17: Speeds for WZ3 on westbound I-70.

Figure 18 shows delays experienced by drivers along each portion of the work zone under study. Again, the color coding is similar to what is used in Figure 7. Delays at all parts of the subject work zone are shown to be negligible (below one minute). In comparing delays on each portion of the work zone, attention should be paid to the fact that different segments are of different lengths and therefore reported delays most probably need to be normalized based on the unit length for a valid comparison.

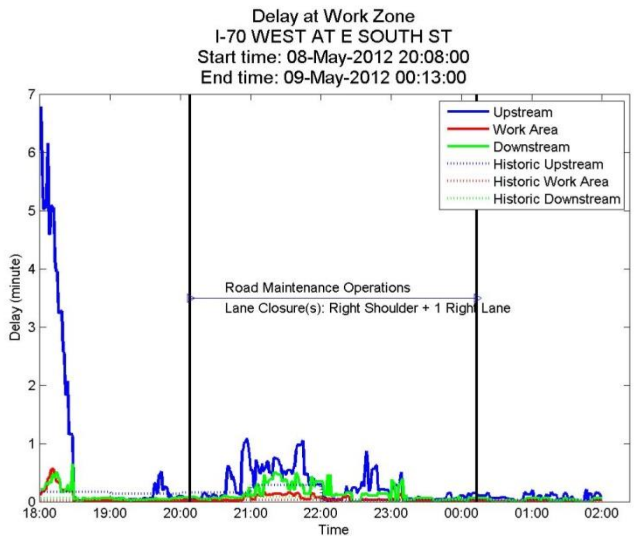


Figure 18: Delays for WZ3 on westbound I-70.

Figure 19 shows queue lengths formed on each portion of the work zone under study. The color coding is similar to what is used in Figure 7. In this Figure, queue lengths are additive. This means that reported queue lengths are the summation of queue lengths in each TMC segment. Figure 19 suggests that less than mile long queues in the downstream segment and 1.5-2.0 mile long queues in upstream portions of the work zone are detected frequently during this work zone road closure. From 9:00 pm to 10:00 pm, the whole length of the work area (0.20 mile long) is queued up.

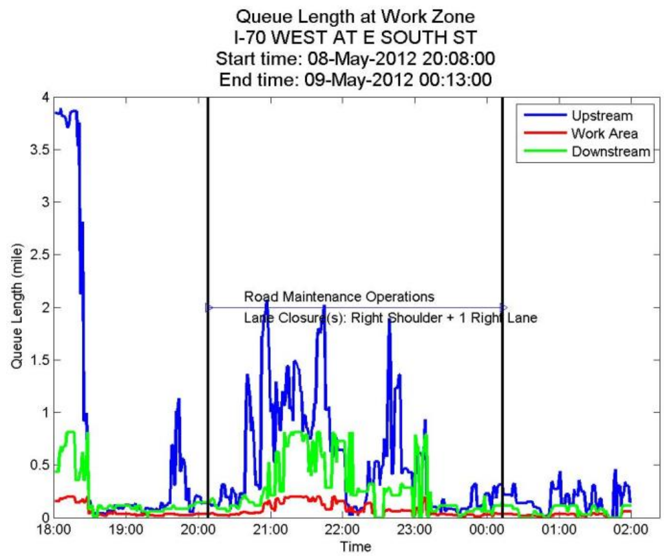


Figure 19: Queue lengths for WZ3 on westbound I-70.

Figure 20 shows the length of connected queues formed (according to the criteria defined in the methodology section) on each portion of the work zone under study. The color coding is similar to previous Figures. Figure 20 suggests that connected queue length is a more stable measure of traffic queue lengths in comparison with the simple additive queue lengths measure. In fact, imposing the connectivity criteria leads to a general decrease in the frequency by which a queue is reported. At the same time, it keeps the major queues intact. In this case, the reported lengths of queues on upstream segments are significantly reduced after imposing the connectivity criteria. Again, the longest queues during the work zone operation period are reported in the downstream and upstream segments while the work area seems to be fully queued up for some portions of the work zone activity.

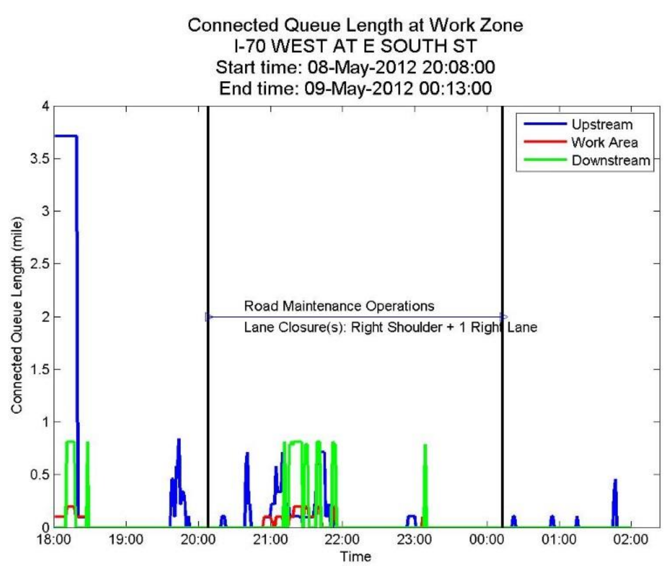


Figure 20: Connected queue lengths for WZ3 on westbound I-70.

Figure 21 exhibits the congestion flags and corresponding alert messages in the third investigated work zone (WZ3) identified in the westbound I-70 corridor. Figure 21 shows that, during the work zone operation time, congestion was detected multiple times in all parts of the work zone. This caused several alerts to be issued during the work zone related road closure that evening.

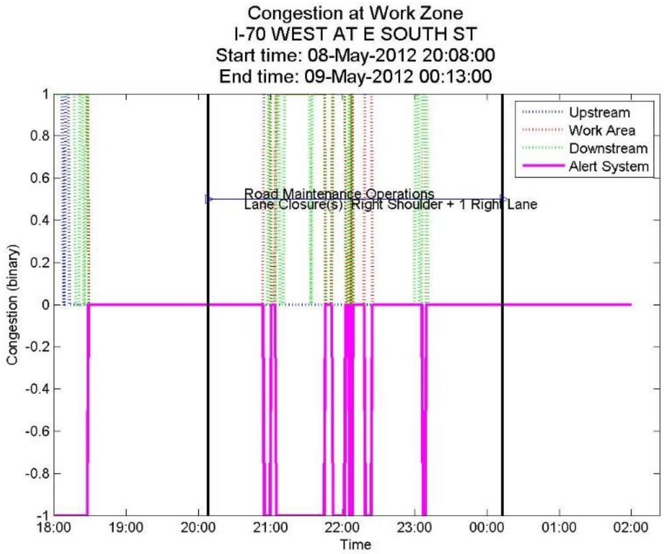


Figure 21: Congestion and alerts for WZ3 on westbound I-70.

2.3.4. I-70 West b/w Exit 62 (MD-75 Green Valley Road) and Linganore Road

Table 13 shows performance measures computed based on speed data in the area of study. The reported performance measures are broken down to measures in each portion of the work zone during the work zone operations (5 hours and 33 minutes = 333 minutes).

Table 13: Performance measures for WZ4 on westbound I-70.

Performance Measure	Unit	Upstream	Work Area	Downstream
Length	Mile	10.66	5.63	2.57
Average Delay	Minute	0.01	0.00	0.10
Maximum Delay	Minute	0.09	0.03	0.25
Queue Duration	Minute	181	6	330
Average Queue Length	Mile	0.03	0.00	0.21
Maximum Queue Length	Mile	0.21	0.07	0.52
Percent Time Queue Length Exceeds 1 miles	%	0	0	0

Figure 22 depicts the observed travel speed variations on each portion of the work zone. The blue color represents speeds upstream of the work zone, while speeds at the work area are represented by red colored lines. The green lines represent downstream speeds. Also, in Figure 22, the real time speeds are depicted using solid lines while dotted lines represent historic speeds. The two vertical black lines identify the start time and end time of the work zone. The general trends and differences between speeds at the upstream, work area, and downstream segments follow the expected trend where speeds generally fall when approaching urban areas. In this case, only the right shoulder of the highway is closed. As seen in Figure 22, the impact of work zone on traffic speeds is minimal.

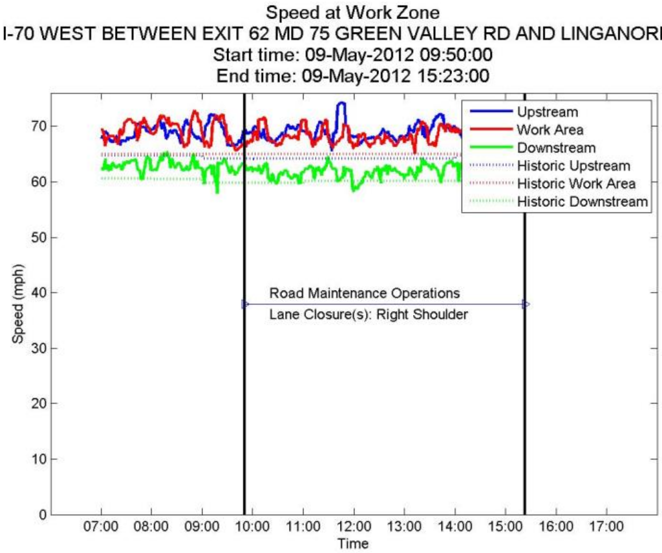


Figure 22: Speeds for WZ4 on westbound I-70.

Figure 23 shows delays experienced by drivers along each portion of the work zone under study. Again, the color coding is similar to what is used in Figure 22. Delays at all parts of the subject work zone are shown to be negligible (less than 20 seconds). The reported delays are generally below expected delays (historical delays -- shown using dotted lines) on any part of the work zone.

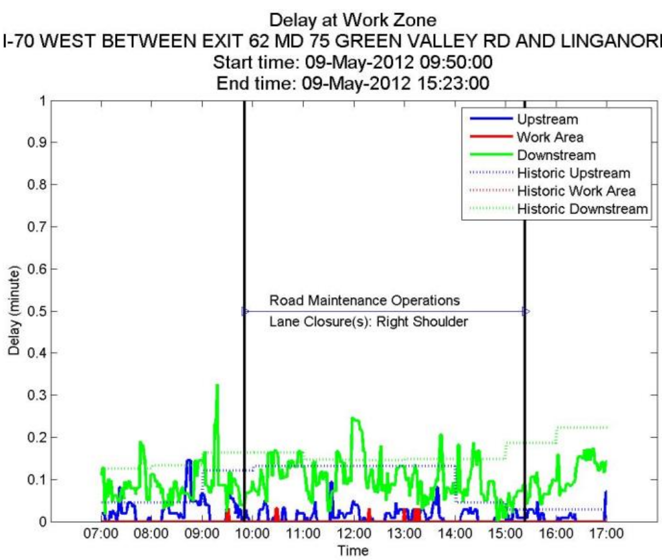


Figure 23: Delays for WZ4 on westbound I-70.

Figure 24 shows queue lengths formed on each portion of the work zone under study. The color coding is similar to what is used in Figure 22. In this Figure, queue lengths are additive. This means that reported queue lengths are the summation of queue lengths in each TMC segment. Figure 24 suggests that in downstream queues formed are typically below half a mile long while queues inside work area and upstream are even shorter.

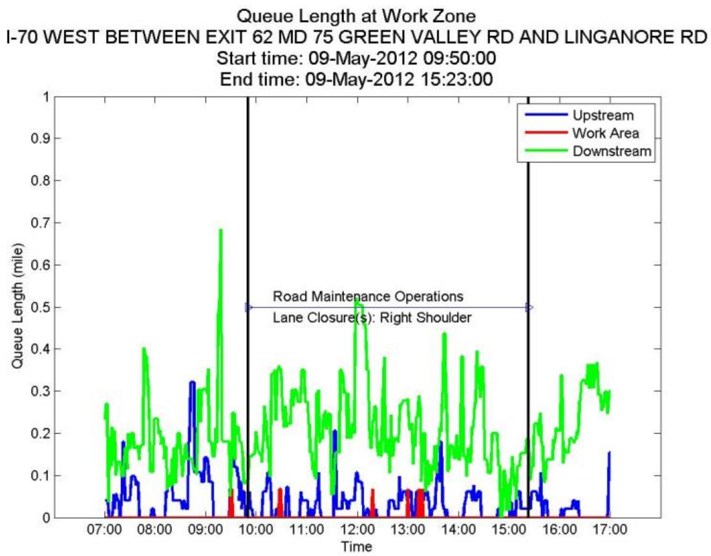


Figure 24: Queue lengths for WZ4 on westbound I-70.

Figure 25 shows the length of connected queues formed (according to the criteria defined in the methodology section) on each portion of the work zone under study. The color coding is similar to previous Figures. Figure 25 shows that no connected queues existed throughout the work zone operation period.

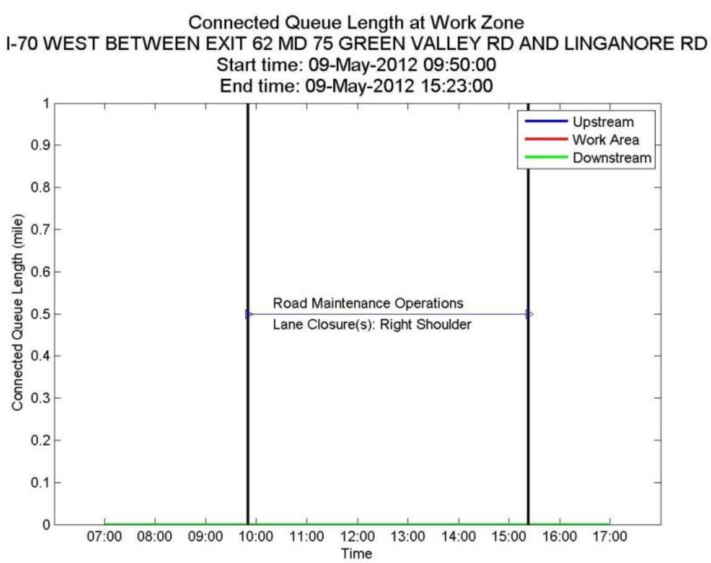


Figure 25: Connected queue lengths for WZ4 on westbound I-70.

Figure 26 exhibits the congestion flags and corresponding alert message in the fourth investigated work zone (WZ4) identified in the westbound I-70 corridor. Figure 26 shows that during the work zone operation time no congestion is reported in any segment of the study area.

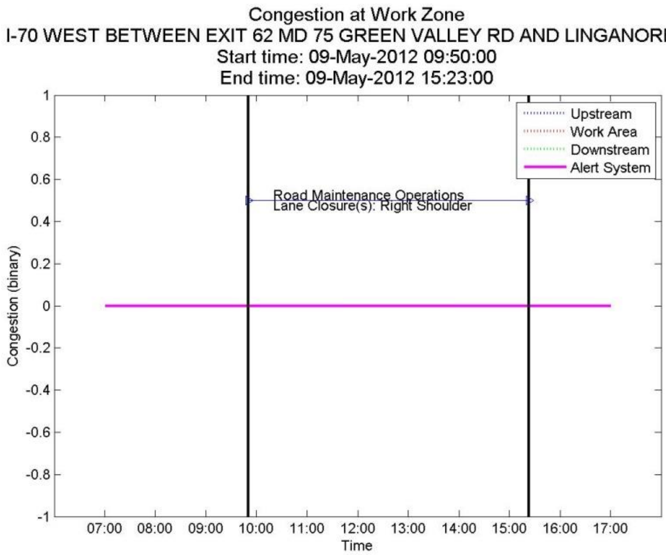


Figure 26: Congestion and alerts for WZ4 on westbound I-70.

3. WORK ZONE PERFORMANCE MONITORING APPLICATION (WZPMA)

This section presents the WZPMA which was developed based on the previously explained methodology to enable real-time monitoring of work zone performance measures. The WZPMA was created using a spiral software development model which allowed for iterative application development and multiple opportunities for design revisions based on customer feedback and usability demonstrations. This approach enabled the developers to improve the WZPMA based on comments from SHA personnel, as well as feedback from other users of the tool. The WZPMA development was organized in eight tasks described in Table 14, and it resulted in a fully operational application housed in RITIS. For access to the tool, please go to www.ritis.org.

Table 14: Tasks for the WZMPA development.

Task 1	Based on initial input gathered from two workshops held with SHA personnel, prioritize a set of WZPMA functions from varying user and use-case perspectives including: • operational (e.g., real-time work zone monitoring and queue alerting), • analytical (e.g., work zone performance measure historical performance and evaluation), and • policy-making (e.g., statewide work zone historical performance and mobility impact assessment). Work with CHART system developers to ingest EORS lane permitting database into RITIS data fusion engine
Task 2	Based on requirements identified in Task 1, prototype a functional WZPMA with a focus on the user interface and alerting functions.
Task 3	Provide training on prototype to select SHA field and office personnel. Run usability experiments with select users to test and validate functionality.
Task 4	Conduct user input meeting to identify WZPMA modifications and/or enhancements.

Task 5	Based on the results of Task 3 usability study and Task 4 user meeting. Develop new version of WZPMA and modify and/or expand SHA field and office personnel to test and validate functionality.
Task 6	Conduct final user input meeting to identify desired WZPMA modifications and/or enhancements.
Task 7	Based on Task 6, develop "final" functional version of WZPMA.
Task 8	Develop WZPMA "User Guide".

The remainder of this section provides some of the key elements of the User Guide which describes functionalities of the final WZPMA product. It is divided into two parts: the Work Zone Dashboard and the Individual Work Zone Profile. Each part starts with an overview of the main screens – layout and general functionality of basic controls followed by a breakdown of each element (or widget) on those screens. Screenshots of the application are used for easy reference. The next five figures provide screen shots and explanations of the Work Zone Dashboard, which are followed by another six screens and descriptions of the Individual Work Zone Profile.

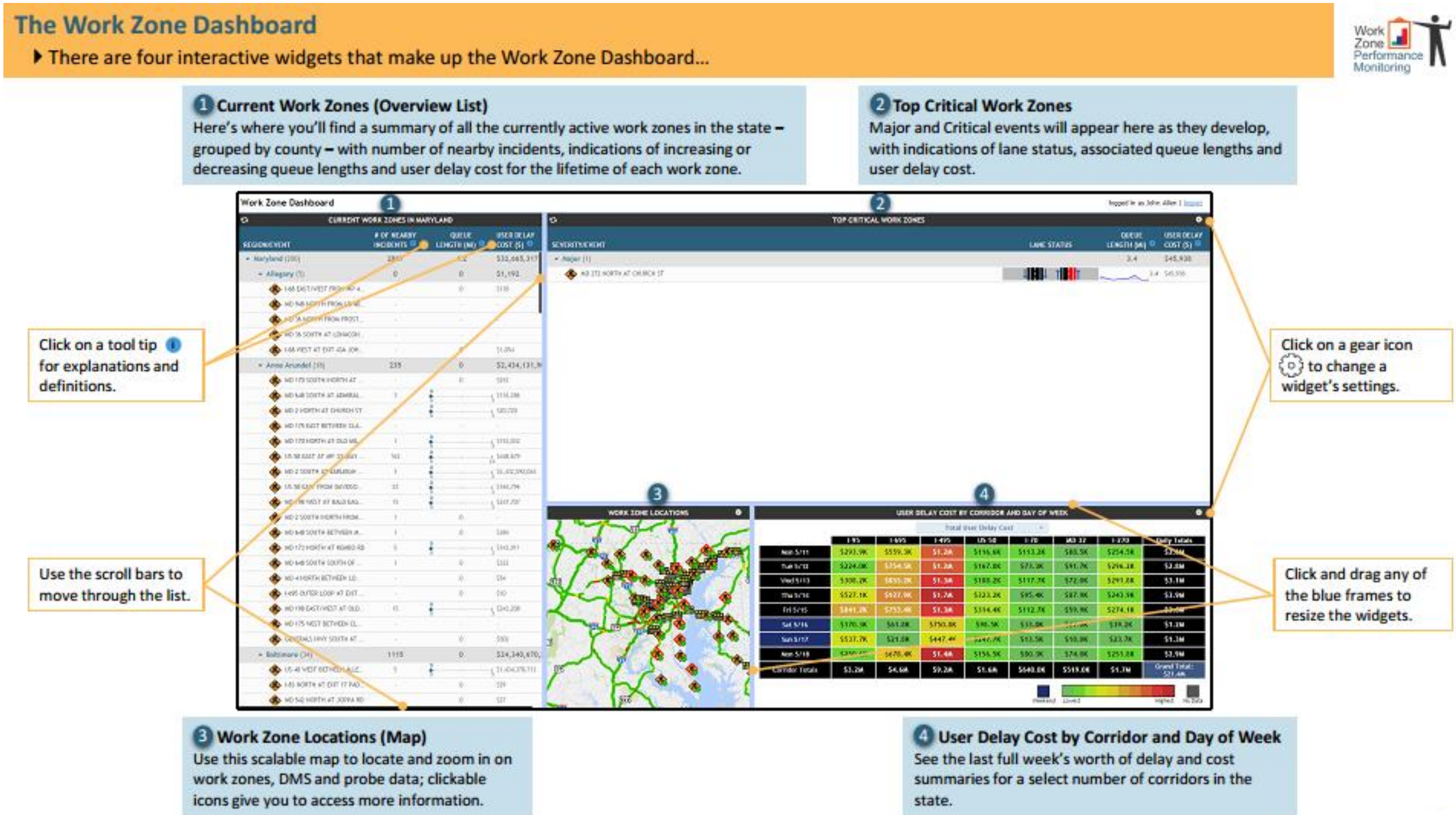


Figure 27: An overview of the work zone dashboard

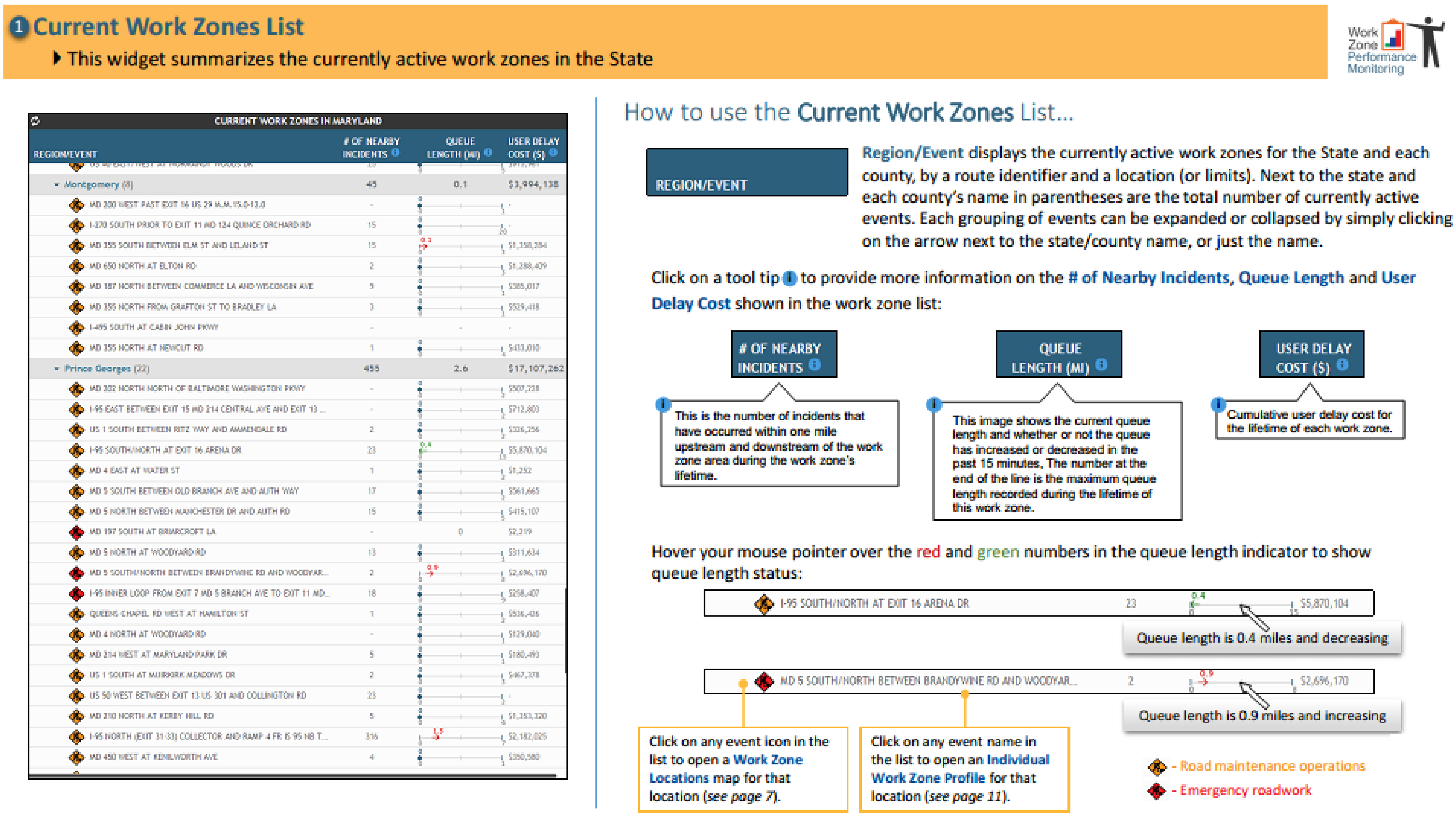


Figure 28: An overview of the work zone dashboard (Current Work Zones List)

2 Top Critical Work Zones

- This widget shows the top work zone locations by severity

Work Zone Performance Monitoring

How to use the Top Critical Work Zones Widget...

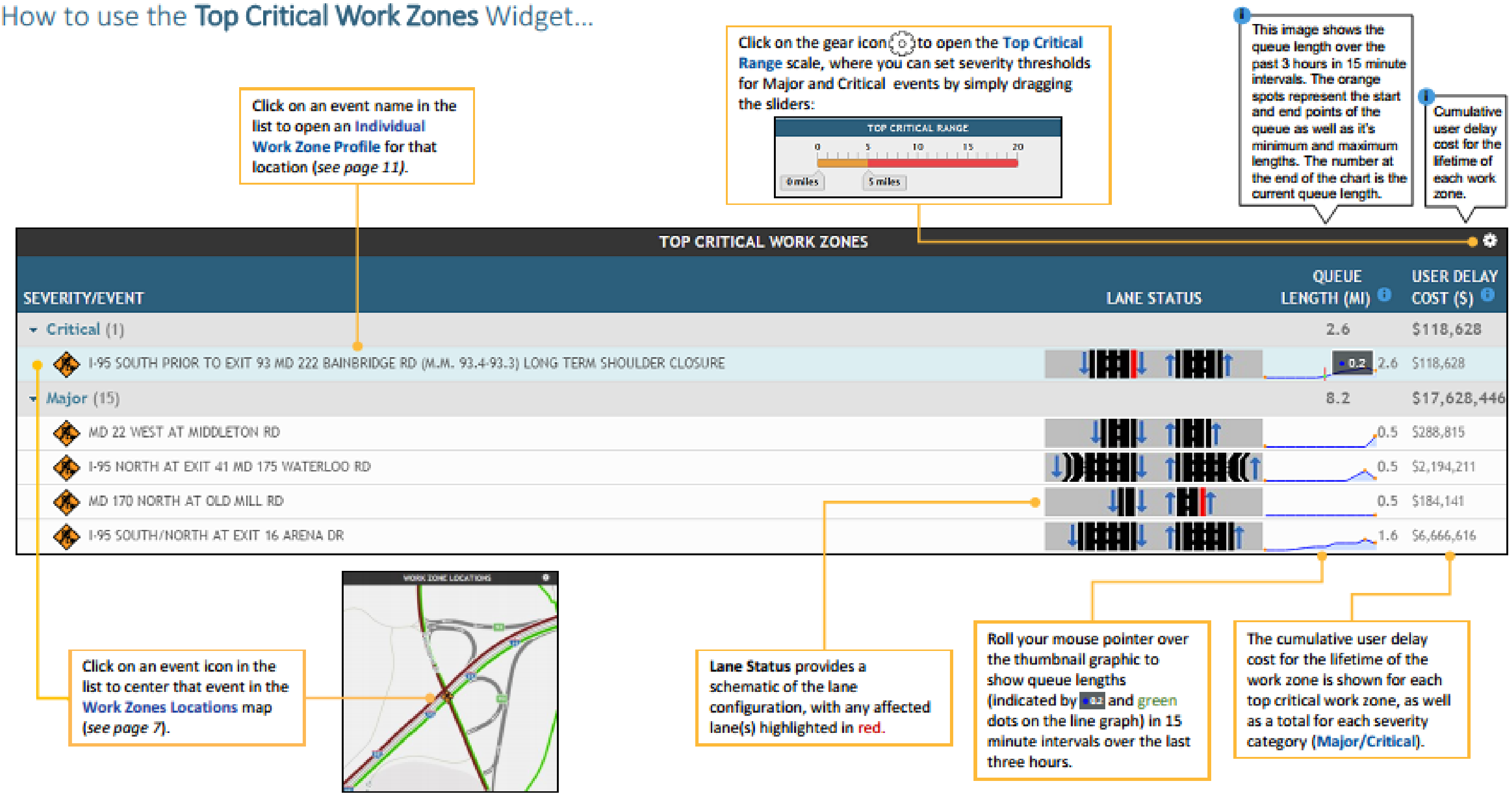


Figure 29: An overview of the work zone dashboard (Top Critical Work Zones)

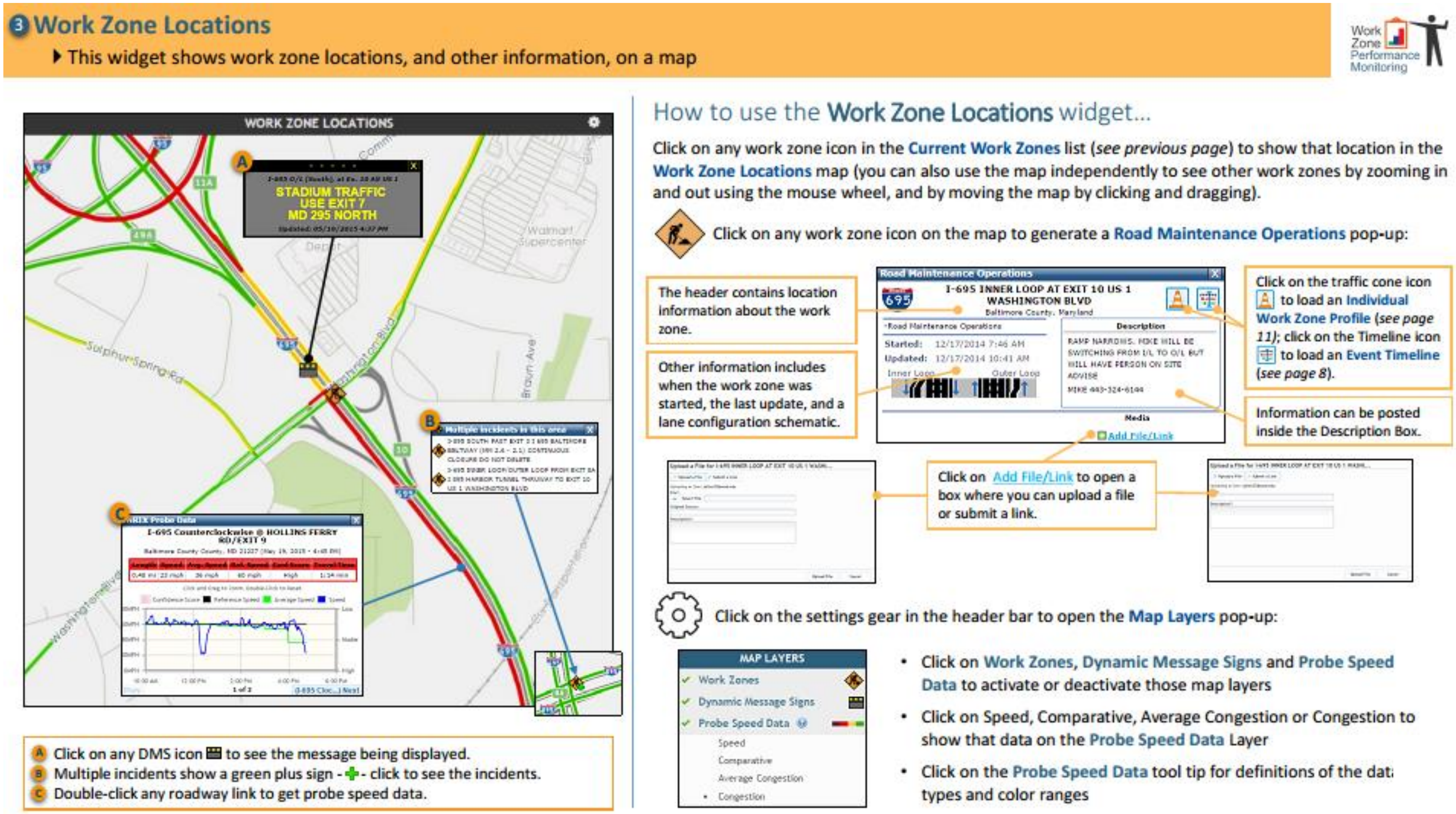


Figure 30: An overview of the work zone dashboard (Work Zone Locations)

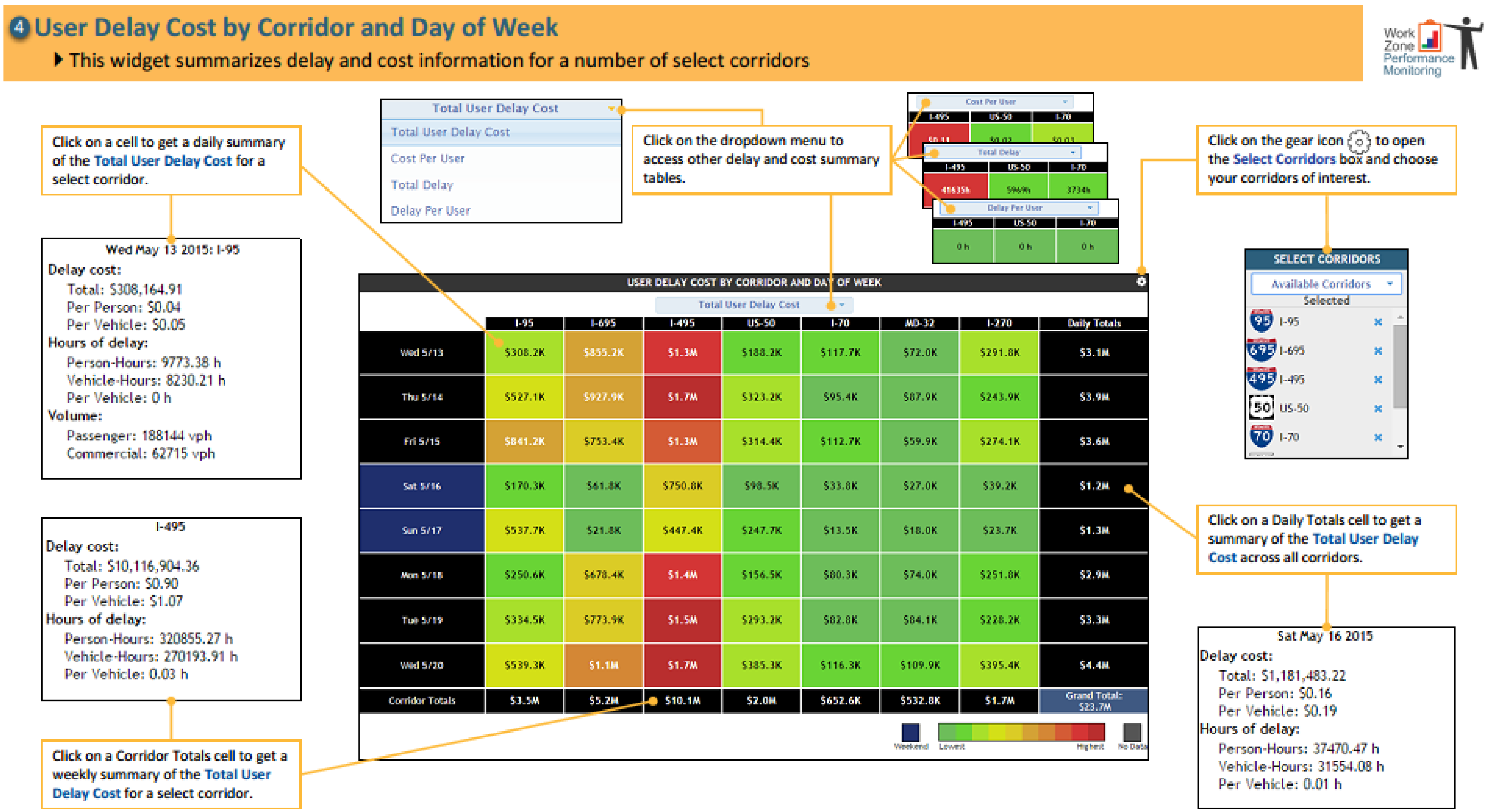


Figure 31: An overview of the work zone dashboard (User Delay Cost by Corridor and Day of Week)

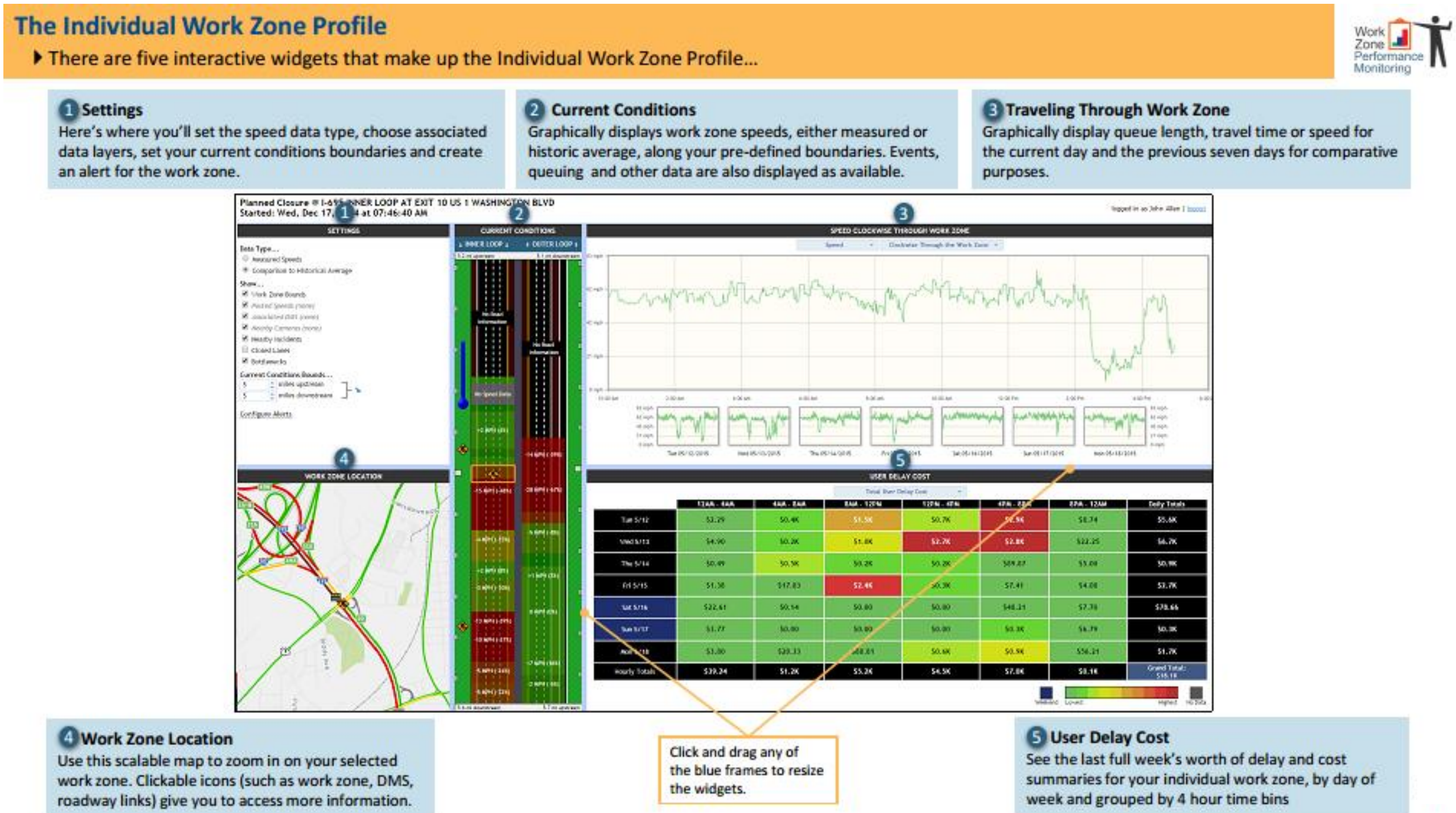
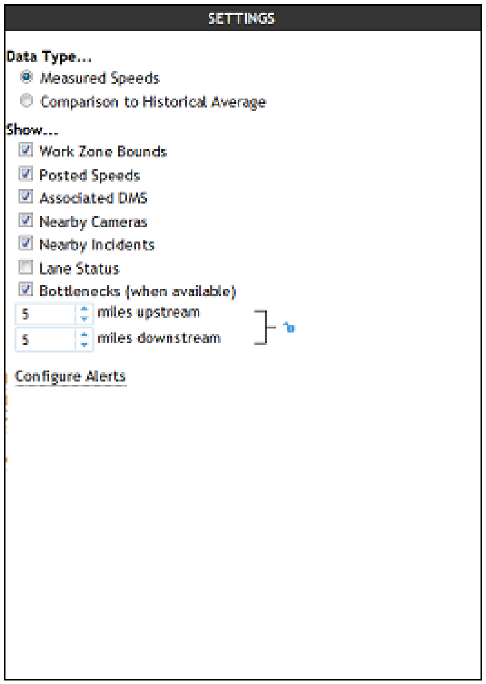


Figure 32: An overview of the individual work zone profile

1 Settings

- This widget allows you to set a number of parameters for an individual work zone



How to use the **Settings** List...

Data Type...

Choose to view the current conditions measured speeds, or a comparison to the historical average:

Measured speed – average speeds shown along the TMCs of the predefined roadway segment **(e.g.; 35 MPH)**

Historical Average – comparison of the average speed to the historical average, with percent change (e.g.; **-26 MPH (-65%)**)

Show...

Simply check the desired boxes to show a number of different data layers:

- ☑ **Work Zone Bounds –** draws an orange box around the work zone area
- ☑ **Posted Speeds –** shows speed limit signs along the predefined roadway segment
- ☑ **Associated DMS –** shows DMS locations along the predefined roadway segment
- ☑ **Nearby Cameras –** shows CCTV cameras along the predefined roadway segment
- ☑ **Nearby Incidents –** shows the location and type of nearby incidents
- ☑ **Lane Status –** indicates any lane closures along the predefined roadway segment
- ☑ **Bottlenecks (when available) –** shows location, direction and length of any bottlenecks along the predefined roadway segment

Using the up/down arrows, indicate how far upstream and downstream from the work one you want to view (click on the lock icon to lock these limits in place)

Configure Alerts

Simply check the desired boxes, adjust any parameters and add your contact info to receive individual work zone alerts:

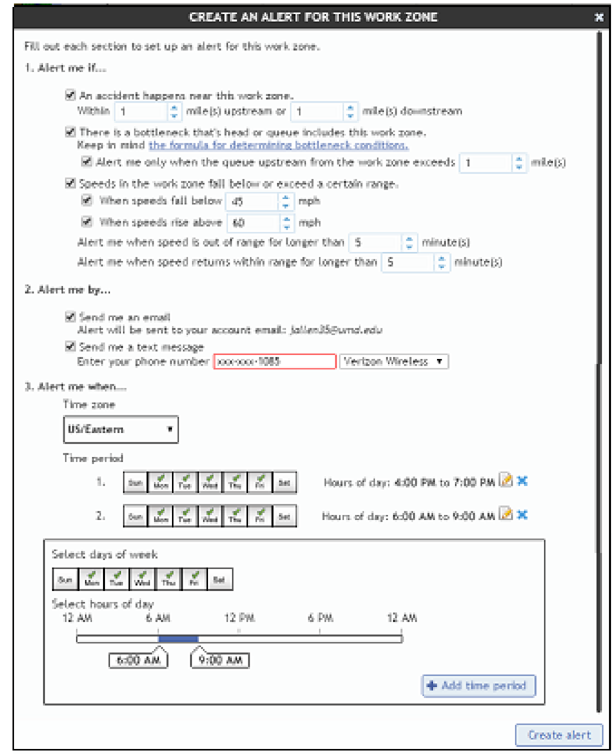


Figure 33: An overview of the individual work zone profile (Settings)

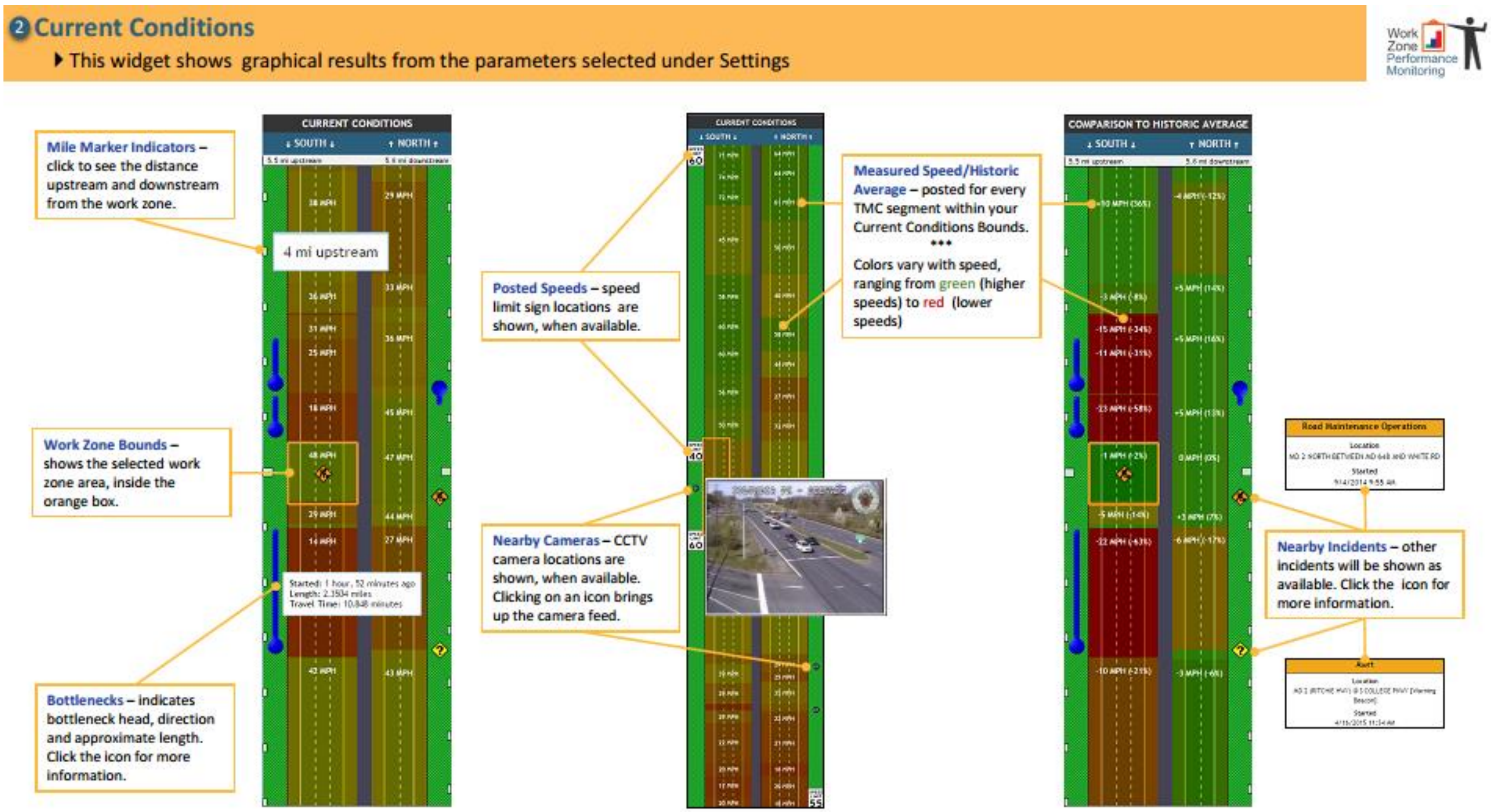


Figure 34: An overview of the individual work zone profile (Current Conditions)

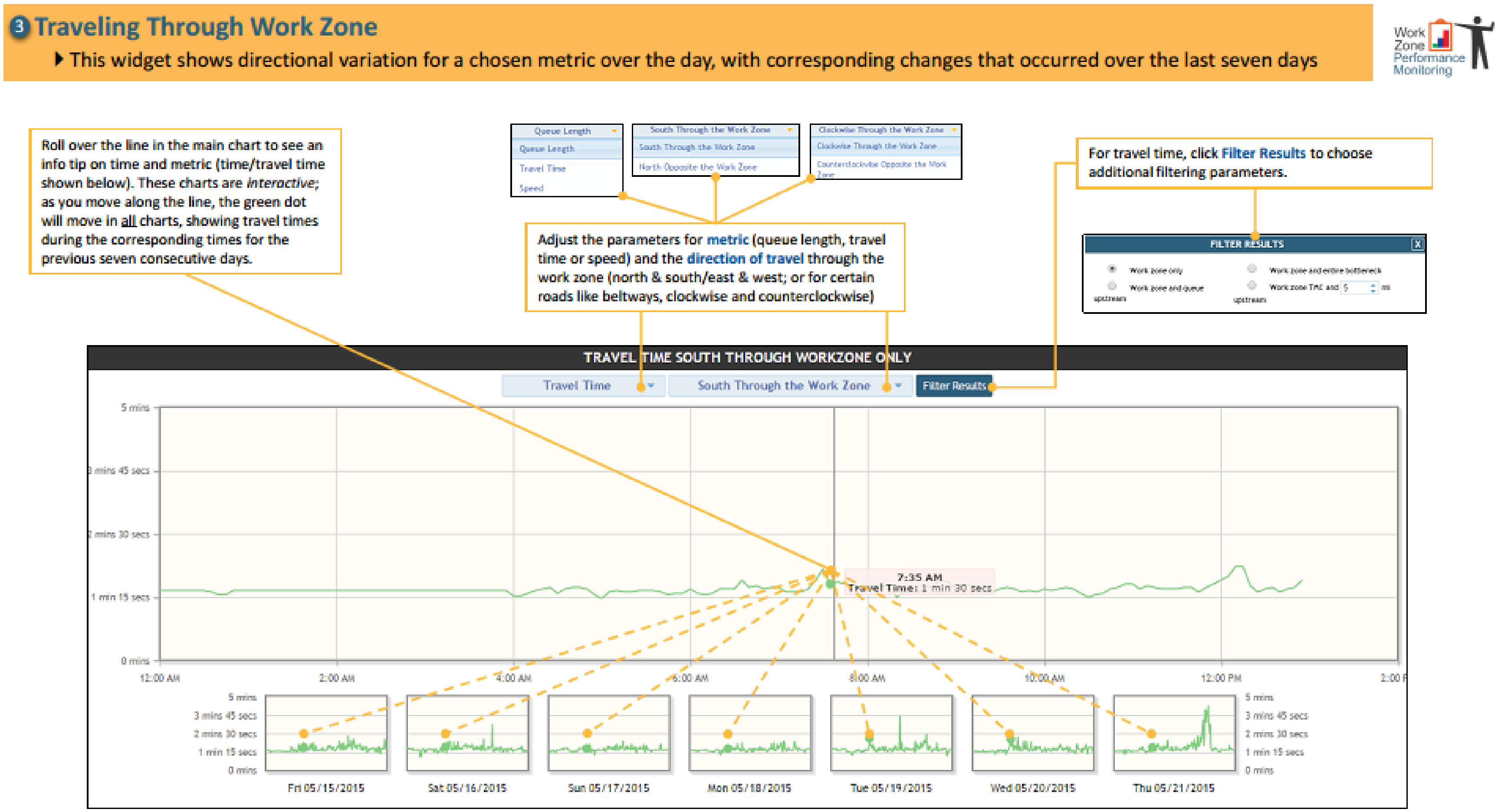


Figure 35: An overview of the individual work zone profile (Traveling through Work Zone)

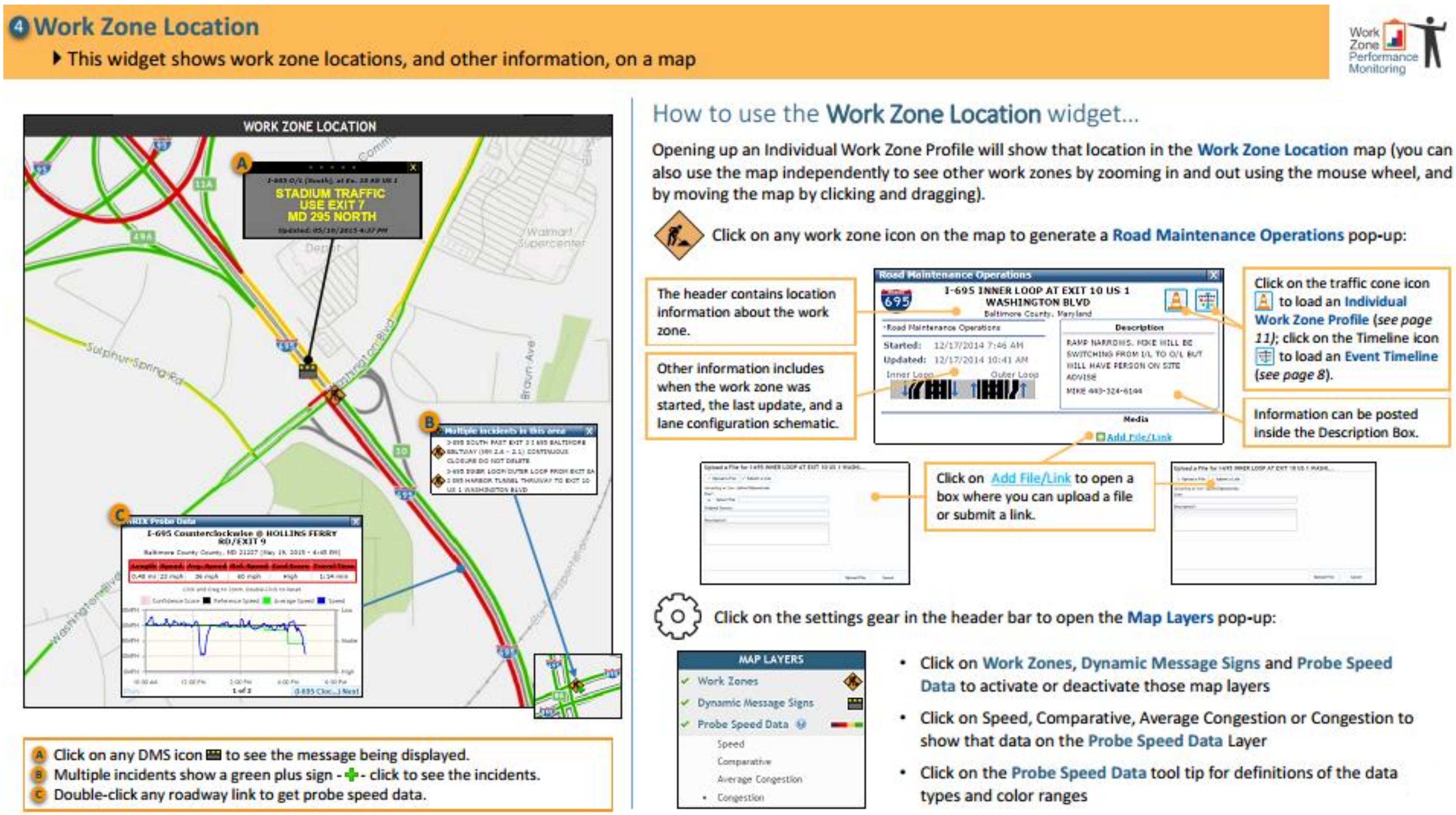


Figure 36: An overview of the individual work zone profile (Work Zone Location)

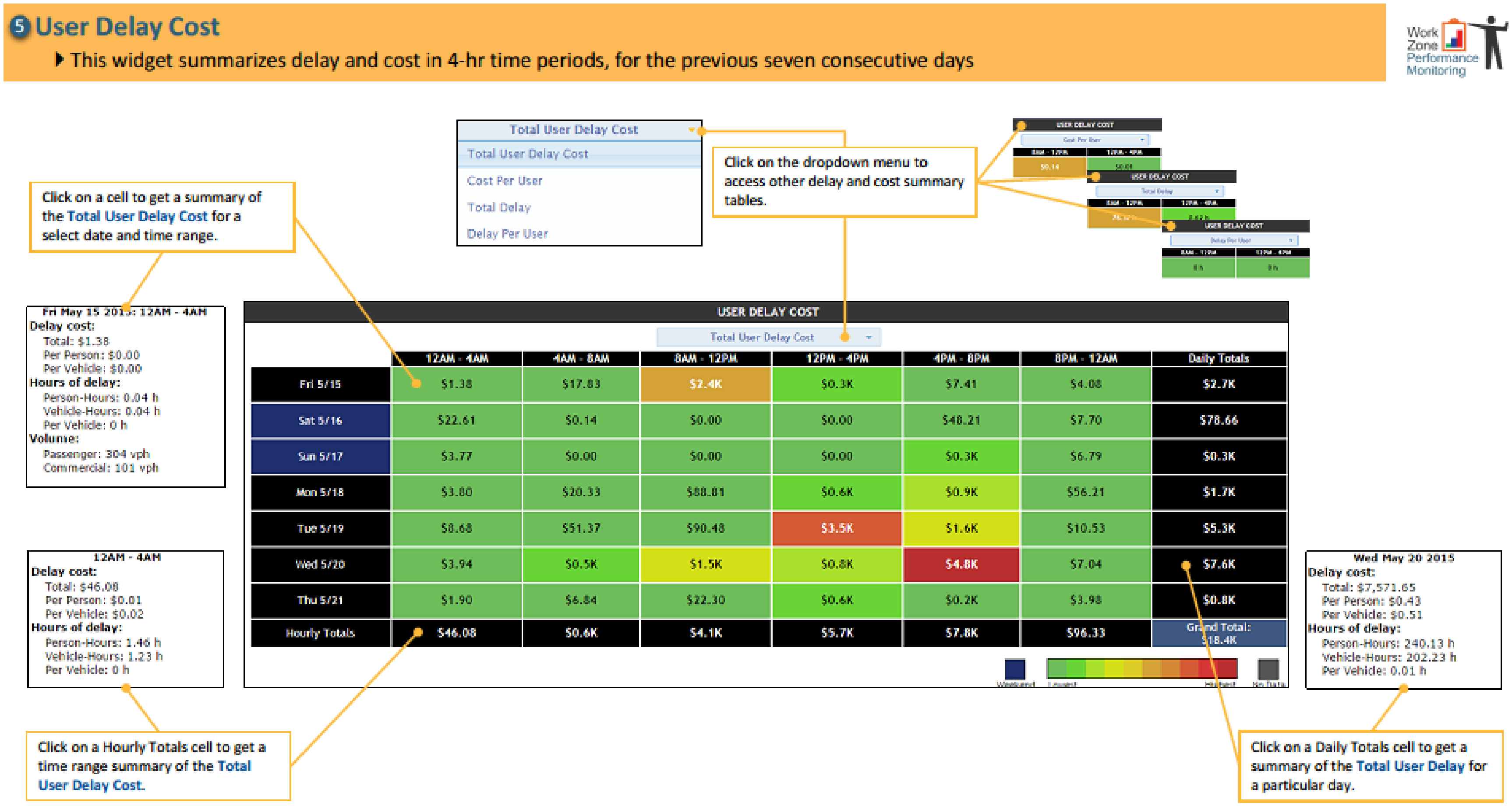


Figure 37: An overview of the individual work zone profile (User Delay Cost)

4. CONCLUSIONS

The WZPMA was developed for SHA as a real-time performance monitoring tool for work zones using INRIX vehicle probe data and active work zone information provided by the SHA CHART system. The WZPMA allows SHA to comply with the Final Rule on Work Zone Safety and Mobility by offering a simple, effective and systematic approach to assessing and managing work zone impacts of projects. In particular, using the tool to monitor and assess work zone performance helps facilitate efficient management and evaluation of work zone impacts throughout project development and implementation. Benefits of the WZPMA are:

- For Project Engineers and Managers
  - Real-time performance monitoring
  - Alerts when thresholds are exceeded
  - Actionable, multi-layered data
- For Planners & Decision-makers
  - Work zone/closure delay and cost summaries
  - Performance assessment (to improve processes and procedures, data and information resources and training programs)
- For Public Relations
  - Easily compare real-time and historical performance
  - Fast response to inquiries and complaints

The University continues to work with SHA Office of Traffic & Safety to get the WZPMA tool deployed to the user community.

5. REFERENCES

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Project Description. (2012). Retrieved from http://apps.roads.maryland.gov/WebProjectLifeCycle/ProjectInformation.aspx?projectno=FR4275110#

Ullman, G. L., Lomax, T. J., & Scriba, T. (2011). *A primer on work zone safety and mobility performance measurement.* Federal Highway Administration.