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Mitigating Work Zone Incidents and Improving Work Zone Safety Through ITS Technologies

Submitted By:

Brian Staes, Master’s student, USF
Elzbieta Bialkowska-Jelinska, PhD student, USF
Fidelis Victor Almeida De Souza, Master’s student USF
Rakesh Rangaswamy, PhD student, USF
Sindy Paola Marsiglia Barrios, Under Graduate student, USF

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6	Performing Organization Name and Address	University of South Florida, 4202 E Fowler Ave, Tampa, FL 33620
7	Primary Contact	Rakesh Rangaswamy Mob: +1 813-397-9089
8	Faculty Advisor	
9	Project Team Members	Brian Staes, USF Elzbieta Bialkowska-Jelinska, USF Fidelis Victor Almeida De Souza, USF Rakesh Rangaswamy, USF Sindy Paola Marsiglia Barrios, USF
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11	Abstract	Infrastructure in the United States is decaying at a rate where continual maintenance and, in some cases, new construction is needed to ensure the safety of all its inhabitants. This dilemma is especially potent towards transportation infrastructure. On a daily basis, there is maintenance or construction occurring across the country to maintain safety and improve mobility, which, in turn, requires the use of work zones during these operations. Work zones themselves, may it be on a bridge, at an intersection or along an arterial, both exhibits flow restrictions to the traffic stream and requires the users to be more cautious and aware while driving through them. Typical safety components of a work zone include items that create a safe environment for the workers as well as the users, such as road barriers, pavement markings, and specialized traffic signs. Although these safety measures are employed at all work zones, there is still a significant volume of vehicular crashes, and in more severe cases, worker and user fatalities. Based on past crash data, some contributing factors to crashes in work zones include excessive speed, ignoring posted work-zone signs for lane merges and closures, and disproportionate user compensation narrower lanes due to shoulder and median work. With these recurring attributes of work zone related crashes known, the deployment of mitigating strategies that use ITS solutions, smart work zones (SWZ), has become a pushing force for a safe user operating and worker improvements. The purpose of this report is to not only identify what current ITS solutions exist in mitigating work zone related incidents but to pinpoint ITS solutions that are currently being developed, which can drastically improve the pandemic work zone related incidents.

1. Description of Problem

1.1 Background and Motivation

The roadway infrastructure in the United States (US) is reaching a tipping point. In November 2019, The Status of the Nation's Highways, Bridges and Transit report to congress, identified the current infrastructure conditions in the US. It found that of the nation's National Highway System roadways, which included most principal arterials, weighted by lane miles, between 25-40% were identified to have fair or poor ride quality, cracking, rutting or faulting. Additionally, of the roadways funded from Federal-aid highway funding, which included most principal arterials, urban collectors, or major rural collectors, again weighted by lane miles, it was found the same variables were slightly higher, with 60% of these roadways exhibiting fair or poor ride quality and 43% having fair or poor cracking. (FHWAa 2019). The continual deterioration of the nation's roadways is evident; the need to maintain these roadways will require extensive work. As such, all roadway work that occurs requires the use of work zones (WZ), which have consequences of their own.

In 2018, there were 755 fatalities directly related to work zones in the US (Figure 1). In 2016 and 2017, more than half of work zone fatal crashes (51%) in the US occurred on arterial roads, followed by interstates (39%), collector, and local roads (10%) (National Work Zone Safety Information Clearinghouse). It should be mentioned, too, of the nation's roadways, arterials, collectors, and local roadways comprise 98.5% of all roadway miles. Moreover, these roadways receive 67% of all vehicle miles traveled in the US (FHWAa 2019). It is identified that work zones in the United States significantly contribute to the fatalities and crashes that occur annually, and thus safety therein should be a major priority.

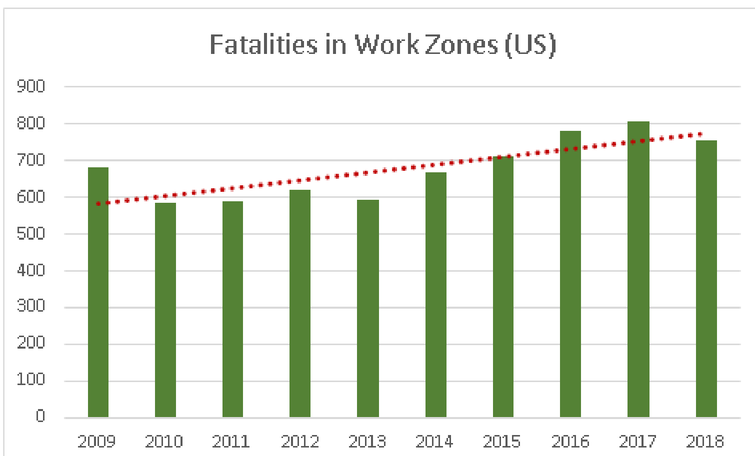

Figure 1 Work Zone Fatalities in the US (2009-2018)

The basic intention of a roadway is to provide safe and efficient transport of people and goods. The safety implications of work zones were previously discussed. However, the efficiency of these work zones needs to be mentioned. The FHWA represents the congestion that occurs in work zones as non-recurrent congestion. As such, it was identified that work zones comprise nearly a quarter of all non-recurrent congestion and roughly 10% of all congestion in the United States, which amounts to 482 million vehicle hours of delay annually (FHWAb 2004). Moreover, 439 urban areas, 2011 induced 4.8 billion hours of additional travel, requiring the use of an additional 1.9 billion gallons of fuel, which amounted to $101 billion dollars (Schrank, Lomax, & Eisele, 2011). Although these values are for the 439 urban areas within the study and include congestion from all sources, if work zones contribute 10% of all congestion and 25%

of all non-recurrent congestion, it can be stipulated that work zones may have broader impacts outside of urban areas even though there is no data to implicity confirm this.

Lastly, In the American Association of State Highway and Transportation Officials (AASHTO) and Strategic Safety Plan (SHSP), works zones are given significant priority. As noted by the Federal Highway Administration (FHWA) in traffic systems management and operations perspective, more congestion occurs in work zone areas resulting in an increase in crash rates. Although there are crashes that occur that are directly associated with the work zone itself, there is a scenario where the congestion, which occurs because of the work zone, heightens the chance of crashes to occur. The crash risk and prevalence of congestion due to work zones depict the priority to solve this dilemma on the nation's roadways.

1.2 Introduction

Work zone (WZ) setup and management are essential for all roadway projects. Whether the WZ is for recurring maintenance, reconstruction, or for new infrastructure, it is key to provide a safe and efficient environment for both the road users and workers within the confines of the WZ. Driving conditions inside of work zones require more attention than normal traffic operations. As such, special, work zone related traffic signs, appropriate barriers, pavement markings, law enforcement, construction vehicles, and workers, either assist or directly manage the work zone. Although some or all of these components are utilized in work zones to mitigate these crashes, the individual attributes which influence crashes inside of work zones need to be identified.

A preliminary assessment of work-zone-related crash data (CARS 2012–2017) suggests the following general contributing factors:

1. Disregarding traffic signs for lane closures
2. Exceeding posted speed limit for lane shifts/crossovers
3. Over-correcting for work on shoulders or medians
4. Exceeding posted speed limit for intermittent WZs

With the identification of key variables that influence work zone related crashes, Intelligent Transportation Systems (ITS), which combat these distinct situations need to be addressed.

The integration of ITS technologies within work zones is considered a Smart Work Zone (SWZ). SWZ concepts produce data-driven traffic management and provide increased safety for traffic, workers, and pedestrians. SWZ systems have been around for more than 20 years, but within the last ten years, the systems have become more robust and accessible. These systems are portable and automated with temporary components that obtain and analyze traffic flow data in real-time, providing frequently-updated information to motorists Bledsoe, Raghunathan, & Ullman, 2014). SMZ systems may include temporary measures such as queue detection, speed monitoring, construction equipment alerts, travel time display, incident detection, and surveillance, temporary overheight vehicle warning or a combination of these technologies (Bledsoe et al., 2014; Ullman, 2017; Ullman, Schoeder & Gopalakrishna, 2014).

The integration of SMZ concepts has the potential to impact the roadway user and construction worker; it will also play a role in the construction and consulting transportation agencies that bid on any project which requires roadway work. Depending on the type of work zone required for the project, the components that make up the SMZ may alter to fit that work zone type. As such, the equipment used therein would change. There is an additional component that may be reduced, too; when bidding on projects, there is a section related to road user costs. The SMZ is utilized to reduce the risk of crashes within work zones and the congestion that occurs as a result of the work zone. If these hold true, the practitioners may be able to reduce the road user costs by implementing SMZ concepts.

2. Project Objectives

- Identify available ITS solutions that can be quickly assembled and deployed at work zones to combat the four major factors which contribute to work zone crashes.
- Create a "package" of ITS solutions that, when used together, mitigate all four key areas that were identified to cause work zone crashes.

3. Approach

The research team will identify ITS solutions that can be deployed rapidly and reused in an array of work zone locations regardless of the availability in existing infrastructure. Furthermore, each ITS deployment needs to have existing literature on its effectiveness in solving the particular issue at hand. For instance, the ITS deployment, which is intended to reduce the number of drivers who exceed the posted speed limit inside of work zones need to have evidence through empirical data that the solution works. The product from the project is a "package" of ITS solutions that, when used together, mitigate all four key areas that were identified to cause work zone crashes. A final mention of the cost estimate to either rent or purchase these devices will then be discussed along with the implication this package would have on prospective stakeholders.

4. Problem Statement

Roadway Infrastructure in the United States is in a position where continued maintenance and, in some cases, reconstruction is needed. The continual and future road work that needs to be accomplished generates the necessity to analyze work zone safety and efficiency. Smart work zone concepts, which comprise of ITS solutions working in tandem, are then identified to mitigate the four prominent challenge areas associated with work zone safety, and to also reduce the congestion caused therein.

5. Description of the Solution

This section introduces the proposed smart work zone awareness device with the other two existing smart applications and each of their operations. Functional architecture, physical architecture and enterprise architecture are described in section

5.1 Smart Work Zone Awareness Device (SWAD)

A SWAD is a smart work zone application that has posted speed limit sign (static sign), speed feedback sign (LED display), and four flashing beacons. All the signs are mounted together in a trailer, as shown in Figure 2. This application warns drivers of work zone activities and speeding behavior with speed limit details. SWAD can be deployed anywhere that excessive vehicle speeds are a concern. SWAD device is similar to Active Work Zone Awareness Device (AWAD) and can be used on highways, rural and urban areas, and it is portable and easy to handle and deployable. The basic operation of SWAD are as follows:

- Install SWAD in the upstream of the work zone area.
- Configure and activate the speed radar and speed message display as per the posted speed limit.
- Activate the flashing beacons when the driver in the work zone area drives over the posted speed limit.

Figure 2 Example of Smart Work Zone Awareness Device (SWAD)

5.2 Portable Changeable Message Signs (PCMS)

A PCMS device is a ITS application that displays a real-time message or information to drivers approaching a work zone area. This device can accommodate different messages based on traffic scenarios. PCMS devices help to draw the attention of drivers to hazards identified by warning signs. Although PCMS with speed display may be used on all types of highways and work zones, irrespective of rural or urban environments, PCMS deployment is recommended, particularly for rural and urban multi-lane divided high-speed roadways. Studies suggest that the majority of drivers pay attention to displayed messages (Edara et al., 2014), and color-blind-friendly and color-coded PCMSs are more effective than alphanumeric (Banerjee et al., 2019). PCMS are used to inform drivers on the conditions within WZ and remind them of speed compliance. An example of PCMS is shown in Figure 3. The basic operation of PCMS are as follows:

- Display information that motorists can read and comprehend in a short time.
- Keep viewing distance as per the sun position, geometric design of the roadway, and environmental conditions.
- To place the PCMS on the same side of the roadway when multiple PCMS are used to avoid driver distractions.

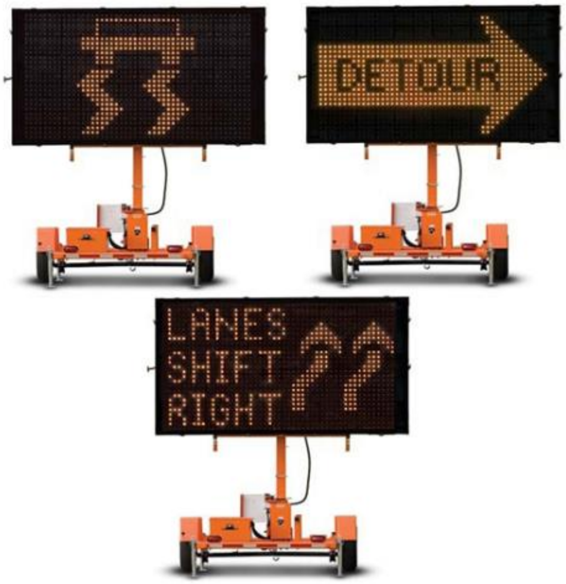

Figure 3 Example of Portable Changeable Message Signs (PCMS)

Source: https://images.app.goo.gl/Lc7gHPdB3z2GwnH59

5.3 Queue Length Detectors System (QLDs)

A QLDs device, also known as Queue Warning Systems, warns drivers of slow or stopped vehicles ahead. It uses infrared beams and can be applied in any work zone where queues form. This device gives information about whether a vehicle has stopped or slowed down by considering the time taken by the vehicle to cross through the device's infrared beams to a certain pre-set time. This technology uses sensors, changeable message signs, cameras, rumble strips. This system is used to improve safety within WZ and decreases the number of rear-end crashes (Ullman et al., 2014). An example of QLD system is shown in the Figure 4. The basic operation of this system are as follows:

- Collect real-time vehicle data
- Analyze data using software's
- Alert drivers of traffic conditions such as delay time, stopped traffic conditions, alternate route options, etc.

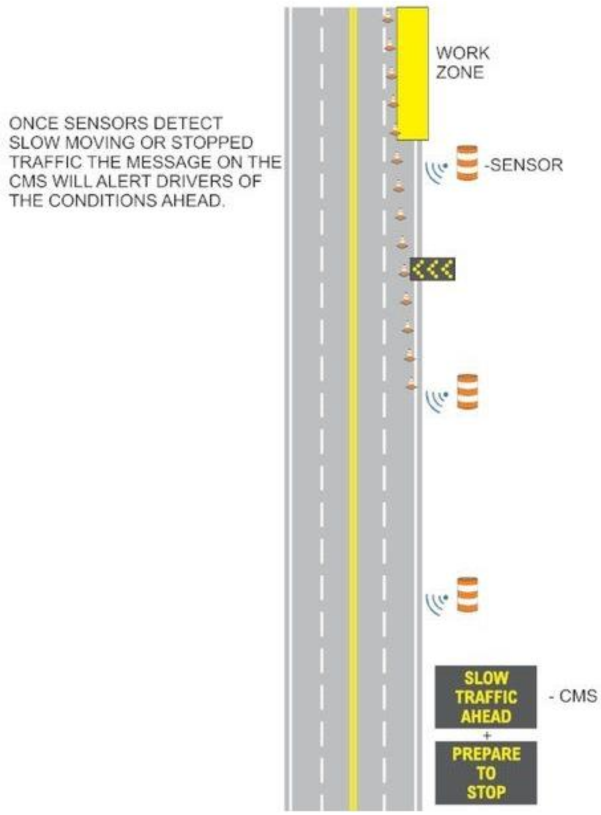

Figure 4 Example of Queue Length Detector System (QLDs)

Source: https://images.app.goo.gl/zKGsAnjzb3eXbH6t5

Example of QLD signages

Table 1 Examples of Queue Length Detection System

Traffic Conditions	Message (Phase 1)	Message(Phase 2)
No congestion	NO DELAY TO US XX	ROADWORK XX MILES AHEAD
Speeds < xx mph	SLOW SPEEDS AHEAD	PREPARE TO STOP
Significant Delays	XX MIN DELAY	NEXT XX MILES
Even Greater Delays	XX MIN DELAY	CONSIDER ALT ROUTE
Delays > Threshold Value	EXPECT MAJOR DELAYS	ALT ROUTE EXIT XXX

6. Functional Architecture

The project team, with the guidance of the Center for Urban Transportation and Research, ITS team, propose the below smart work zone applications. A generic deployment layout of the SWAD application is shown under the physical architecture section.

6.1 SWAD

A SWAD device should be placed in the advance warning area, as shown in the figure (), but close to the work zone area (300 ft-350 ft). By providing this sufficient warning distance for motorists helps in reducing their speed when they approach the work area. SWAD devices should be placed behind guardrails and barriers or delineated by cones or barrels.

6.2 PCMS

The deployment of PCMS devices should be closest to the lane for which the message applies, between the initial warning sign and in advance of the work area. Usually, the device is deployed on the shoulder or in the median, preferably behind guardrails or concrete barriers. If guardrails and barriers are unavailable, cones or barrels should be used to increase the visibility of a PCMS, which is similar to SWAD devices. PCMS devices usually are deployed at the upstream of the advance warning area, as shown in Figure 5, to provide sufficient warning distance to motorists so they can have enough time to react to the warning message.

6.3 QLD's

Queue length detectors should be placed in the upstream of the work zone area, as shown in Figure 5, such that it allows the travelers to choose an alternate route based on the displayed information. An additional location could be added if required to provide road users with additional information. Messages such as "STOPPED TRAFFIC AHEAD," "BE PREPARED TO STOP," STOPPED TRAFFIC XX MILES AHEAD" should be displayed when traffic slowed beyond a specified threshold.

7. Physical Architecture

Figure 5 is an example of the implementation of ITS technology in a work zone area at an intersection. Work zones may involve lane closures, detours, and moving equipment. They are set up according to the type of road and the work to be done on the road and vary by duration and WZ type. There are four major WZ types—1) lane closure, 2) lane shift/crossover, 3) work on shoulder or median, and 4) intermittent (i.e., mobile operations). The proposed solution can be implemented in all these types of work zone types.

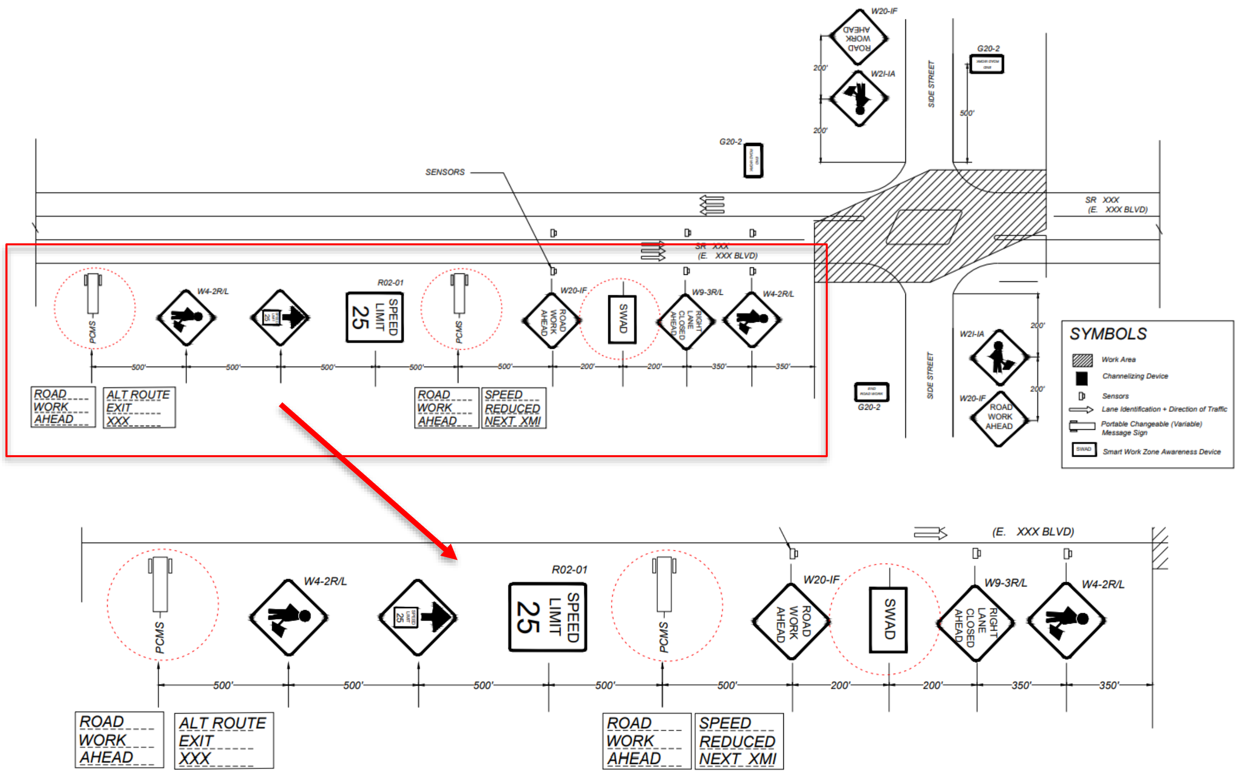

Figure 5 Physical Architecture of Smart Work Zone

8. Cost and Estimation

Table 2 Cost and Estimation of proposed ITS technologies

Basis of Estimates				
Description	Item	Cost ($)	Unit	Deployment (Days)
Smart Work Zone Awareness Device (SWAD)				
Posted Signs	0700 1 40	300.00	AS	1
Speed Feedback Sign with Flashing Beacons	0700 11262	14,965	EA	1
Portable Changeable Message Sign (PCMS)				
PCMS	102 099	10.68	ED	1

The Queue Length Detector system, which comprises vehicle sensors, PCMS, cameras, and rumble strips, requires more advanced systems and would include software that is capable of communicating in real-time with the roadway sensors. Additionally, the application of these systems may require the installation of additional detectors in the roadways if they are not already present, which may incur additional costs. In total, depending on if new detectors need to be installed and the cost for the Queue Length Detector system can range from $125,000 to $200,000 (Ullman et al., 2014).

9. Timeline

All these systems require little to no installation, however transporting the devices to the site. For the installation of roadway sensors, it may take longer but it is anticipated to take roughly a day to set up this system for a work zone.

10. Evaluation plan

To evaluate the safety performance of the proposed ITS applications, For an after data analysis should be conducted. The safety measures that should be used to assess the safety performance of the proposed ITS applications are 85th Percentile Speed, Average Speed, speeding rate, speed variance, sudden deceleration rate, and the statistical methodologies to be used in the before-after comparisons is

$$H_0: X_{with} \geq X_{without}$$
$$H_a: X_{with} < X_{without}$$

where X*with* is the crash risk (negative equivalence of safety performance) with an ITS application scenario, and X *without* is the crash risk without the ITS application scenario. If the null hypothesis (H*0*) is rejected at a given confidence level (for example, 95%), it can be determined that the proposed ITS application implementation can improve work-zone safety.

11. Conclusion

Roadways in the United States are aging and require extensive repair. In order to repair these facilities work zones are used to provide a safe environment for the worker and driver alike. Work zones, although necessary to complete roadway Maintenance and repair, work zones themselves create the environment for crashes and cause congestion. A solution was proposed that includes either one or a series of ITS solutions, Smart Work Zones, which can be implemented to mitigate both crashes and congestion within work zones.

11.1 Safety Benefits

ITS can help to minimize the consequences of work zones on both traveler and worker safety. Implementation of the proposed SWZ system will provide additional warning information for drivers who approach the WZ areas. The benefits include improvement in speed limit compliance, by a reduction in speed within the work zone, drivers will have the opportunity to react when a vehicle slows down at lower speeds, thus reducing the number of rear-end crashes.

11.2 Operational Benefits

Using ITS technology in work zones can effectively divert traffic from the mainline, producing improvements in the overall operation. During times of very heavy congestion, motorists will follow the diversion guidance posted on message boards. Large percentages of traffic diverted on several occasions when the system recommended the alternate route.

11.3 Mobility Benefits

Reduced travel time delay is a primary benefit of many work zone ITS applications. Travelers making adjustments to their route, departure time, or mode choices based on information provided by ITS can reduce delay. Due to the inherent capabilities of queue detection systems, roadway users will know when and if there is a queue ahead, which will allow them to decelerate less franticly, which can mitigate congestion.

11.4 Environmental Benefits

Additionally, there will be environmental benefits as cars will sooner get to their destination. The risk of implementing the proposed SWZ systems includes a dependency on electricity and potential hacking to the system.

11.5 Limitations & Risks

A PCMS can be an effective temporary traffic control device when used appropriately. By its very nature, it draws the attention of the motorist; however, this effect can be diminished if this device is overused. The PCMS should not replace any of the signing details in the MUTCD and should not be used if standard traffic control devices adequately provide the information the motorist needs to travel safely.

References:

Banerjee, S., Jeihani, M., Brown, D. D., & Ahangari, S. (2019). Comprehensive Analysis of Dynamic Message Sign Impact on Driver Behavior: A Random Forest Approach.

Bledsoe, J., Raghunathan, D., & Ullman, J. (2014). The Use of Smart Work Zone Technology During Construction of the I-35 / Homestead Lane Interchange in Johnson County Kansas. Retrieved from https://www.fhwa.dot.gov/hfl/projects/ks_swz_i35_johnsoncounty.pdf

Edara, P., Sun, C., Keller, C., & Hou, Y. (2014). Evaluation of dynamic message signs on rural freeways: Case study of a full freeway closure. Journal of Transportation Engineering, 140(1), 89–98. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000614

Federal Highway Administration (FHWAa). (2019). *Status of the Nation's Highways, Bridges, and Transit.* U.S. Department of Transportation. https://www.fhwa.dot.gov/policy/23cpr/pdfs/23cpr.pdf

Federal Highway Administration (FHWAb). (2004). *Making the Work Zones Work Better.* U.S. Department of Transportation. https://ops.fhwa.dot.gov/wz/about/wz_story.htm

Florida Department of Transportation (FDOT). (2020). *Item Average Unit Cost.* https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/programmanagement/estimates/historicalcostinformation/files/historicalitemaverage_12month_20190101-20191231.pdf?sfvrsn=940303c2_2

National Work Zone Safety Information Clearinghouse. https://www.workzonesafety.org/crash-information/work-zone-fatal-crashes-fatalities/#national

Schrank, D., Lomax, T., & Eisele, B. (2011). *TTI's 2011 Urban Mobility Report Powered by INRIX Traffic Data. https://nacto.org/docs/usdg/2011_urban_mobility_report_schrank.pdf*

Ullman, G., Schroeder, J., & Gopalakrishna, D. (2014). Work Zone Intelligent Transportation Systems Implementation Guide. Retrieved from https://ops.fhwa.dot.gov/publications/fhwahop14008/

Ullman, G. (2017). Smart Work Zone Experience and Research in Texas. *AASHTO Subcommittee on Construction Annual Meeting*. Retrieved from https://construction.transportation.org/wp-content/uploads/sites/20/2017/04/2_Ullman_Jerry_Smart-Work-Zone-Experience-and-Research-in-Texas.pdf