Selection and Implementation of Intelligent Transportation Systems for Work Zone Construction Projects

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Abstract: The extent of the deployment of Intelligent Transportation Systems (ITSs) for work zone construction projects has increased in recent years. However, highway agencies are unable to meet the full demand of the deployment of ITSs in work zones in a fiscally constrained environment. Therefore, it is desirable to establish guidelines to help highway agencies to consider installing ITSs in work zones as funding becomes available. The goal of this research is to develop a methodology and guideline to assist project designers in assessing whether a particular work zone construction or maintenance project should be considered for the deployment of one or more ITSs. If so, the guideline would assist in determining the ITSs that would be most appropriate for the project. To achieve this goal, the researchers: (1) investigated technologies and evaluated different ITSs that could be used in work zone projects, (2) selected the criteria that would have to be evaluated to identify the eligible work zone projects for the deployment of ITSs, and (3) developed a selection methodology to assist project designers in selecting one or more work zone ITSs in order to be deployed in the project. The outcomes of this study provide a guideline for use in selecting and implementing ITSs for a work zone construction or maintenance project.

Keywords: work zone ITS; intelligent work zone; smart work zone; system selection; ITS work zone guideline; scoring criteria; work zone critical project characteristics

1. Introduction

A work zone is a segment of a road where roadwork takes place and may involve lane closures, detours and moving equipment. Work zones are necessary parts of constructing, maintaining, and rehabilitating the nation’s transportation infrastructure. As the highway system ages, the need for rebuilding and maintenance increases, and local and state highway agencies are required to implement more work zone projects. As a result, in recent years, there has been a significant increase in the construction and maintenance of highways. While the safe and efficient flow of traffic through work zones is a major concern to transportation officials, industry, the public, businesses, and commercial motor carriers, the work zones usually create challenges related to mobility and safety. Most of the work zone construction and maintenance projects occur during the daylight hours or even nighttime when the traffic is passing through the work site. Work zones often reduce the capacity of the roadway, impede traffic flow, create irregular flow, and cause congestion and delays, all of which reduces the predictability of the driving conditions. Traffic congestion and the resulting delays through work zones are the major complaints of the motorists who are traveling on the roadways. The degraded facilities, lane restrictions, changes in
the configurations of the lanes, narrowed lanes, and conflicts between roadway traffic and construction vehicles and workers also can result in safety hazards in work zones that can cause traffic accidents and injuries to both the traveling public and the construction workers. Work zones can have traffic conditions that are unexpected by motorists and that place construction workers dangerously close to fast-moving vehicles. Taken together, all these factors create challenges to the smooth movement of traffic through work zones, so there is a need to apply new strategies to improve the management of traffic in work zones. There are some existing studies on smart work zone design standards and operating procedures. However, no comprehensive procedure was found to help both in selecting and implementing Intelligent Transportation Systems for work zone construction projects. Therefore, the scope of this research covers: (a) developing a selection methodology to assess whether a particular project should be considered for work zone ITS deployment, and (b) developing a guideline to assist in determining the work zone ITSs that are most appropriate for the project.

2. Background

Work Zone Intelligent Transportation Systems (ITSs) offer highway agencies the opportunity to reduce work zone-induced congestion, improve safety, and reduce the severity of crashes. Over the last decade, a few agencies have used the technology on a few construction or maintenance projects, and they based their decisions on specific problems that arose or on negative experiences that occurred on a previous project located nearby. Departments of Transportation (DOTs) in various states have installed ITSs in their work zones to manage the traffic and to mitigate the adverse impacts experienced by construction and maintenance workers and travelers [1]. Work zone ITSs are automated systems of devices that involve the use of a broad range of communications-based information and electronics technologies and provide accurate, real-time information to motorists and workers. These systems make it possible to anticipate and significantly reduce work zone-induced congestion, thereby making the areas in and around work zones safer. Information provided by the work zone ITS may be in the form of real-time traffic conditions, such as travel time through a work zone, or recommended diversion routes that motorists can use. In addition, work zone ITSs can be used to provide immediate warnings to the drivers that the traffic is stopped ahead, or provide warnings that a slow truck is entering from a work zone, or warn workers that a vehicle is intruding into their work area. Work zone ITS also can be used to control traffic through various devices and technologies, such as variable speed limit signs, ramp metering, dynamic lane merge system, and portable signal systems [2].

Successful implementation of ITS applications in work zones requires systematic guidelines to assist project designers in making the best decisions. Several highway agencies and States’ Departments of Transportation have developed manuals and guidelines for work zone ITS. For example, the Colorado Department of Transportation (CDOT) developed Design Guidelines for Including ITSs on Projects [3]. The guidelines include individual information about single components of ITS (e.g., changeable message signs, closed circuit television cameras (CCTVs), vehicle detectors, fiber optic cable and conduit) and five different ITSs. The Minnesota Department of Transportation (MnDOT) and the New Hampshire Department of Transportation (NHDOT) have prepared work zone ITS Toolboxes as guidelines for selecting appropriate ITSs for existing work zone traffic issues and to mitigate anticipated issues on scheduled projects [4,5]. MnDOT and NHDOT have divided work zone ITSs into three categories based on detectable stimuli, i.e., “Traffic Responsive Systems”, “Vehicle Responsive Systems”, and “Environmentally Responsive Systems”. Each toolbox consists of 12 work zone ITSs, and most of these systems are common in the two guidelines. In the toolboxes, each system has been described in a separate sheet that includes warrants, benefits, options, and the layout of the individual system. Although the goal of the toolboxes is to help in selecting an appropriate system for a work zone, no selection methodology was presented by the DOTs other than providing
individual descriptions of each of the systems. The Federal Highway Administration (FHWA) published a document to provide guidance on implementing ITS in work zones in order to assist public agencies, design and construction firms, and industry, including developers, manufacturers, distributors, packagers, and providers of devices, systems, and programs [1]. As a part of the document, FHWA drafted a general set of scoring criteria to establish the feasibility of work zone ITS. It also presented nine possible work zone ITS applications in a matrix format for use in considering various critical characteristics of projects. The Connecticut Department of Transportation (CTDOT) presented the basic guidelines for the consistent and uniform usage of work zone ITS projects through its Smart Work Zones (SWZ) Guide [6]. The Guide provides an introduction to SWZ concepts, components, goals, and objectives to be pursued by CTDOT, as well as an overview of different SWZ applications to be used by the state. It also outlines the roles and responsibilities of the different entities involved in the process of implementation of SWZ. The Guide identified and suggested nine ITSs and used the same critical project characteristics table from the FHWA work zone ITS guideline to show potential situations and possible mitigation measures. To more consistently deploy SWZs, the Massachusetts Department of Transportation (MassDOT) developed a Concept of Operations (ConOps) for a SWZ Program [7]. This ConOps guides planners and designers in determining whether an SWZ should be applied to a project, and, if so, the recommended SWZ application to be deployed. The aim of the SWZ Program is to consistently consider and apply work zone ITSs to all construction work zones that meet a specific impact level and pre-set scoring criteria. MassDOT used the scoring criteria drafted by FHWA and developed its own criteria.

The goal of this research was to develop a selection methodology to assist project designers in assessing whether a particular project should be considered for work zone ITS deployment, based on the identification of needs of specific users or travelers. If so, the guideline would assist in determining the work zone ITSs that would be most appropriate for the project. To this end, the research had the following specific objectives, i.e., (1) to investigate technologies and evaluate different ITSs that are deployed in work zone projects, (2) to select the criteria (related to motorists and work zone projects) that are required to be evaluated in order to identify the eligible work zone projects for the deployments of ITSs, and (3) to develop a guideline to assist project designers in selecting work zone ITSs in order to be deployed in the project.

3. Methodology

ITS technology can be used to help in addressing many work zone challenges and can take many forms in the work zone applications. Work zone ITSs can be categorized into three groups based on the functions:

- work zone ITSs to provide necessary information to travelers and drivers;
- work zone ITSs to provide warning to drivers or traffic management centers, which prepare them to respond to the traffic conditions;
- work zone ITSs to control or manage traffic through work zones.

The authors conducted an extensive literature search and reviewed all the ITSs [8–30]. Among the systems, 12 systems were identified that had potential to be used in work zone projects. Each work zone ITS is a collection of components that have been combined to produce a useful, intelligent system. The components’ functions include the detection and collection of the data, transmitting the data, storing and managing the data, analyzing the data, and providing the data to motorists. Table 1 lists the work zone ITSs and their functions along with the common ITS components contained in each system. As seen in the table, portable changeable message signs have a key role as one of the main components in almost all the work zone ITSs. The portable changeable message signs are capable of displaying a variety of messages to inform motorists of unusual driving conditions.
| Work Zone ITS                  | Description                                                                                                                                   | Components                                                                 | Function |
|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|----------|
| Speed Advisory                | Informs drivers of the speed of traffic in advance of the Work Zone (WZ) and helps them make better decisions to slow down sooner or divert to an alternate route. | Non-intrusive Detection, Portable Changeable Message Sign (PCMS), Communications |  ●       |
| Travel Time Estimation        | Obtains real-time traffic data and predicts the current travel time on a section of the roadway downstream along the WZ.                        | Non-intrusive Detection, Video Camera, PCMS or Portable Hybrid Message Sign, Highway Advisory Radio/Websites/Telephone System, Communications |  ●       |
| Construction Vehicle Warning  | Helps to identify that construction equipment is entering/exiting the work area and notify motorists.                                          | Non-intrusive Detection, PCMS, Communications                                  | ●        |
| Excessive Speed Warning       | Warns drivers if their speed is unsafe and alerts them that they are exceeding the advisory speed.                                            | Non-intrusive Detection, Video Camera, PCMS or Portable Hybrid Message Sign, Communications | ●        |
| Hazardous Condition Warning   | Alerts drivers concerning the hazardous conditions in the WZ ahead and advises them of an appropriate action for the situation.               | Non-intrusive Detection, Video Camera, PCMS, Communications                    | ●        |
| Intrusion Detection           | Monitors WZs and alerts both errant drivers and road workers when vehicles or construction equipment enter sensitive sections of the work area, such as areas in which personnel currently are working. | Non-intrusive Detection, Alarm, PCMS, Communications                           | ●        |
| Over-Dimension Warning        | Identifies oversized loads when construction/maintenance causes temporary minimal width or height clearances for large vehicles using the roadway. | Non-intrusive Detection, Video Camera, Alarm, PCMS, Communications              | ●        |
| Stopped Traffic Warning       | This warning is used to monitor the speed of vehicles within and upstream of WZs to alert drivers of traffic conditions ahead.                    | Non-intrusive Detection, PCMS, Communications                                   | ●        |
| Dynamic Lane Merge            | Used to specify a definite merge point in the WZ with lane closure(s).                                                                         | Non-intrusive Detection, Video Camera, PCMS, Communications                    | ●        |
| Portable Signal               | Traffic signals and associated control equipment that can be transported easily and deployed in WZs to improve safety and mobility.              | Non-intrusive Detection, Portable Traffic Signal, PCMS, Communications           | ●        |
| Variable Speed Limit          | Provides the ability to manage the speed of traffic approaching and traveling through WZs based upon either the current traffic conditions or the characteristics of the WZ. | PCMS, Portable Hybrid Message Sign, Communications                             | ●        |
| Temporary Ramp Metering       | Regulates the flow of vehicles on the entrance ramp to the main lanes of the freeway where WZs are located.                                         | Non-intrusive Detection, Portable Ramp Meter, Communications                     | ●        |

Table 1. Work zone ITSs, components, and function.
There are various types of detection that can be used in work zone ITSs depending on the type of the data to be collected. The technologies are radar, pneumatic road tubes, infrared, acoustical, ultrasonic, microwave, magnetic, and piezo-electric technologies, images (photos or videos), radio frequency identification (RFID) technology, license plate recognition, and environmental detectors. In work zone ITSs, communications generally are through wireless technologies, such as cellular phone, radio frequencies, wireless Ethernet, wireless optical, and satellite. Hard-wired communication also is possible in case physical connections are available in the work zone.

3.1. Work Zone ITS Selection and Implementation

Successful implementation of ITS in work zones requires a systematic guideline to assist project designers in making the best decisions for selecting one or more appropriate ITSs for existing work zone traffic issues and to mitigate anticipated issues on scheduled projects. The following sections will present the work zone ITS selection and implementation guideline developed in this study. The guideline is comprised of four steps, i.e., (1) feasibility assessment, (2) identification of the ITS candidates, (3) selection of one or more ITSs, and (4) deployment and evaluation of the ITSs.

3.1.1. Step I: Feasibility Assessment

The first step in work zone ITS selection and implementation process is assessing whether a particular project should be considered for ITS deployment in a work zone based on the identification of specific users’ or travelers’ needs. Several highway agencies developed sets of criteria to establish project feasibility. However, those criteria were developed for particular work zone ITSs, not work zone projects. MassDOT developed its own criteria by using a general set of scoring criteria drafted by the FHWA [7]. The FHWA suggested that highway agencies tailor the criteria as desired for their own use as one possible way to assess the feasibility of ITS [1].

The main step in developing a set of criteria to establish feasibility of work zone ITS is to identify the factors and characteristics that have significant roles in justifying ITSs in a work zone project and may warrant the deployment of a system. The authors used some of the factors and scoring criteria proposed by the FHWA and MassDOT [1,7] and developed a preliminary feasibility assessment tool. After developing the feasibility assessment tool, the authors interviewed and received input from key practitioners and stakeholders in the Texas cities of Austin, Houston, Waco, and El Paso as well as the Texas Department of Transportation’s (TxDOT’s) traffic and transportation engineers, city engineers, county engineers and construction contractors who had been involved directly in or influenced by the work zone projects. Furthermore, several comments were received from construction engineers and managers involved in the projects in Nevada and Colorado. The interviews were conducted face-to-face, via email or telephone. To improve the developed feasibility assessment tool, the interviewees were asked to identify any other factor(s) that should be included, and provide suggestions concerning the corresponding score(s). Table 2 presents the revised work zone ITS feasibility assessment tool, which includes 21 main factors. As mentioned above, the majority of factors and their corresponding scores were adopted from the FHWA and MassDOT. However, the factors and scores were refined based on the results of our interviews, and new factors were added to the list. The tool assists decision-makers by providing a structured approach to considering the need for work zone ITS on specific projects. Once the table is completed for a specific project, all the scores related to the factors are added up to attain the total score. A total score greater than 30 indicates that ITSs are likely to provide significant benefits relative to the associated costs and should be included in the project. A total score between 10 and 30 indicates that ITSs may provide some benefits and should be considered as a treatment to mitigate impacts. A total score smaller than 10 indicates that work zone ITSs may not provide sufficient benefit to justify the associated costs. In this case, the designer should continue the design process without work zone ITS technology. The criteria (10 and 30) are suggested by both...
FHWA and MassDOT, and they were also confirmed in our interviews. The research team developed a flowchart (Figure 1) to illustrate the process involved in the preliminary feasibility assessment of work zone ITS.

Table 2. Work zone ITS feasibility assessment tool including scoring criteria.

| Criteria                                                                 | Score |
|--------------------------------------------------------------------------|-------|
| Factor 1—Duration of construction longer than two years (10 points)       |       |
| • Longer than two years (10 points)                                      |       |
| • Longer than one year (6 points)                                        |       |
| • 6 to 12 months (4 points)                                              |       |
| • 3 to 6 months (2 points)                                               |       |
| • Less than 3 months (1 point)                                           |       |
| Factor 2—Change in roadway capacity (long-term, i.e., greater than 30 days)|       |
| • Loss of one travel lane in both directions (8 points)                  |       |
| • Loss of one travel lane in either direction (6 points)                 |       |
| • Loss of both the right and left shoulders (4 points)                   |       |
| • Loss of the right shoulder (2 points)                                  |       |
| • Narrowed travel lanes (1 point)                                        |       |
| Factor 3—Availability of alternate routes around the work zone           |       |
| • No alternate routes (4 points)                                         |       |
| • An alternate route with available spare capacity (2 points)            |       |
| • Several alternate routes with available spare capacity (0 points)      |       |
| Factor 4—Traffic volume on the roadway                                  |       |
| • High volume, ADT ≥ 50,000 for interstates/freeways and/or >10,000 ADT for 2-lane roadways (10 points) |       |
| • Intermediate volume: between 30,000 and 50,000 ADT for interstates/freeways and/or between 1000 and 10,000 ADT for 2-lane roadways (5 points) |       |
| • Low volume: Less than 30,000 ADT on interstate highways/freeways and below 1000 ADT on 2-lane, 2-way roadways (1 point) |       |
| Factor 5—Posted speed                                                    |       |
| • Greater than 100 kph (3 points)                                        |       |
| • 70 to 100 kph (2 points)                                               |       |
| • 50 to 70 kph (1 point)                                                 |       |
| • Less than 50 kph (0 point)                                             |       |
| Factor 6—Percentage of heavy vehicles                                    |       |
| • Greater than 15% (10 points)                                           |       |
| • 8% to 15% (5 points)                                                   |       |
| • Less than 8% (1 point)                                                 |       |
| Factors 7 to 21—Impact of specific issues (0 to 3 points each, based on judgment) |       |
| Factor 7—Insufficient sight distance                                     |       |
| Factor 8—High speeds/chronic speeding                                   |       |
| Factor 9—Existing crash history within the work zone project             |       |
| Factor 10—Variability of the speed of the traffic                        |       |
| Factor 11—Unusual/unpredictable weather patterns, such as heavy rain, ice, fog, snow |       |
| Factor 12—Frequently changing traffic conditions                         |       |
| Factor 13—Merging conflicts and hazards where the work zone tapers       |       |
| Factor 14—Complex traffic control layout with multiple access points (i.e., ramps or side streets) |       |
Table 2. Cont.

| Criteria                                                                 | Score |
|--------------------------------------------------------------------------|-------|
| Factor 15—Construction vehicle entry/exit speed differential relative to traffic |       |
| Factor 16—Limited offset to median or roadside barrier/guardrail           |       |
| Factor 17—Lane diversion—use of highway crossover or center work zone    |       |
| Factor 18—The road is an emergency route for a hospital                   |       |
| Factor 19—The road work affects the only entrance to a neighborhood       |       |
| Factor 20—The construction work or a part of it is done at night          |       |
| Factor 21—Frequent non-peak lane closures                                |       |

Figure 1. Flowchart used to assess the feasibility of a work zone ITS.

In response to the interviews, the practitioners recommended to take full advantage of the permanent ITS elements available on the roadway for the work zone project. Identification of the existing ITS resources in the corridor or region can help in managing the work zone, in controlling the acquisition of the system, and in controlling the costs involved in the deployment of the system. For example, if there is a permanent traffic detector within or near the work zone that can provide real-time data to help predict and/or monitor traffic conditions, the agencies and contractors can benefit from the availability of the existing resources. Therefore, integration with all the existing ITS infrastructure (such as a detector, camera, or changeable message sign) should be considered as part of the design of the
work zone ITS. In such cases it must be ensured that the existing ITS resources are able to remain operational for the duration of the project.

3.1.2. Step II: Identification of the ITS Candidates

The scoring criteria and the work zone feasibility assessment tool help the project designers to determine some of the users’ needs for the work zone project. After determining that the project is eligible to be considered for the deployment of ITSs, the systems that are candidates for the project must be identified among all the potential work zone ITSs (Table 2) based on two criteria, i.e., the “goal of the ITS on that specific project” and “characteristics of the project”.

A highway agency must set clear goals at the beginning of work zone projects to ensure that the deployment of ITS will satisfy those goals. The primary goal of the deployment of ITS technology might be safety, mobility, or both. Safety would be the desired goal of deploying ITS when undesirable conditions are present that may increase the risk of crashes or other incidents. While mobility would be the goal of deploying ITS when traffic is anticipated to be congested in advance or throughout the work zone due to undesirable conditions. Table 3 lists the primary goals of different work zone ITSs. As an example, the goal of the travel time estimation system is to improve mobility in and around the work zone. However, the goal of the speed advisory system might be both safety and mobility. The users’ needs, goals and objectives for the traffic management components of the construction project should be agreed upon. Afterwards, the critical project characteristics should be documented by the project designer to help in making the decision concerning which specific work zone ITS should be implemented. The authors identified the critical characteristics of such projects paired with specific potential work zone ITSs and listed them in an extensive table that consisted of several pages. Table 4 shows only a snapshot of the main table, but it illustrates how some of the work zone ITSs may be designed to address certain conditions. Similarly, some work zone issues can be addressed through more than one type of ITS. As an example, the speed advisory system could address work zone conditions where the operators of vehicles must reduce their speed to safely negotiate a hazardous condition. However, these same conditions also could be addressed by installing an excessive speed warning system. Table 4 can be used as a guide to assess the current characteristics and the anticipated conditions in the work zone that would help justify the implementation of one or more work zone ITSs.

Table 3. Primary goals of the work zone ITSs.

| Work Zone ITSs                  | Primary Goal |
|---------------------------------|--------------|
|                                 | Safety       | Mobility    |
| Speed Advisory System           | ●            | ●           |
| Travel Time Estimation System   | ●            | ●           |
| Construction Vehicle Warning System | ●         | ●           |
| Excessive Speed Warning System  | ●            | ●           |
| Hazardous Condition Warning System | ●          | ●           |
| Intrusion Detection System      | ●            | ●           |
| Over Dimension Warning System   | ●            | ●           |
| Stopped Traffic Warning System  | ●            | ●           |
| Dynamic Lane Merge System       | ●            | ●           |
| Portable Signal System          | ●            | ●           |
| Variable Speed Limit System     | ●            | ●           |
| Temporary Ramp Metering System  | ●            | ●           |
Table 4. Critical project characteristics in a work zone.

| Work Zone ITS | Critical Project Characteristics |
|---------------|----------------------------------|
| Temporary Ramp Metering System | • |
| Variable Speed Limit System | • |
| Portable Signal System | • |
| Dynamic Lane Merge System | • |
| Stopped Traffic Warning System | • |
| Over Dimension Warning System | • |
| Intrusion Detection System | • |
| Hazardous Condition | • |
| Warning System | • |
| Excessive Speed Warning System | • |
| Construction Vehicle | • |
| Warning System | • |
| Travel Time Estimation System | • |
| Speed Advisory System | • |

Temporary ramp geometry has an inadequate length of acceleration lane. Vehicles inadvertently may follow a truck off the roadway due to the high volume of traffic or insufficient sight distance. A hazardous driving condition is predicted such as flash flooding, impaired visibility due to smoke or fog, slippery or rough conditions, or falling rocks or other debris. The work zone may cause regular, recurring delays in excess of 15 min. Traffic must reduce speed to safely negotiate a hazardous condition. Two lanes of traffic must merge into one lane. Traffic operations must be controlled along a two-lane, two-way highway where one lane is closed and alternating traffic movements are necessary. The roadway volume is above the level where the traffic must suddenly adjust speed or change lanes. The location of the day's work activities does not always require a reduction in speed. Step or slowing traffic is not expected, particularly when visibility is restricted.

Based on the users’ needs and the primary goal(s) of the project documented by the project management team and the project designer (Table 3), along with the critical project characteristics (Table 4), the work zone ITS candidates are identified among all the potential systems (Table 1). In this step, it is suggested to take into consideration which performance measures are required for each work zone ITS to be studied later in case the system is selected and deployed in the project. This will provide more information for the project designer and better prepare the agency to assess the work zone operation after the deployment of the ITS. Based on the potential positive impacts, the performance
measures can be categorized into three groups, i.e., (1) mobility/operational performance measures, (2) safety performance measures, and (3) customer satisfaction. Table 5 lists all the performance measures and illustrates their relationships with different work zone ITS. As an example, delay per vehicle, queue length, and volume (throughput) are mobility performance measurements for a dynamic lane merge system. For the same system, crash frequency is a safety performance measurement, while users’ complaints are a measure of users’ satisfaction. To study the performance measures and evaluate the effectiveness of work zone ITSs, agencies must collect and analyze safety and operational data. This helps in providing the information that is necessary to better understand the performance of the systems in work zones. Table 6 lists the different types of work zone ITS performance measures that can be used to address the system’s performance. As an example, for queue length (which is a mobility performance measure), the agency requires that data be collected from sensors (i.e., the presence of vehicles, speed), visual inspection (i.e., site observation), or photo/video images (i.e., cameras).

3.1.3. Step III: Selection of One or More ITSs

In Step II, the candidates for the work zone ITS and the corresponding performance measures were identified along with the type of data that must be collected to evaluate each candidate after the deployment. Step III describes selecting one or more systems to be deployed in the work zone project. Two main factors have significant roles in selecting the final system for deployment, i.e., (1) the benefits of the work zone ITS and (2) the associated costs of the system. Work zones create various issues, e.g., reduced capacity of the roadway, congestion, irregular traffic flow, and the delays of travelers. In addition, the construction activities in the presence of traffic can lead to safety hazards. The ultimate goal of the deployment of a work zone ITS is to make travel through and around work zones safer and more efficient for the motorists and to make the environment in the work zone safer for the construction workers. Regarding the benefits, work zone ITSs provide actionable information to the motorists and workers that reduce risks, delays, and congestion, thereby improving safety. Each work zone ITS has its own non-monetary benefits. For example, the speed advisory system:

- advises the drivers of an appropriate speed to allow them to travel through the work zone with minimal braking;
- smooths the transition between faster and slower moving traffic;
- reduces the lengths of queues and decreases the potential for traffic crashes (rear-end collisions) in the work zone approach area;
- provides an increase in capacity of the roadway through the work zone area.

The authors identified the non-monetary benefits of each system and included them in a table. For the sake of brevity, Table 7 lists only two benefits for each work zone ITS. The complete list will be published in an individual research report.

The cost of the deployment of a typical work zone ITS depends on several factors, i.e., the scope of the overall work zone, the number of components (sensors, cameras, portable changeable message sign, etc.) used in the system, the duration of the construction, the extent of changes to construction staging, and others. According to CTDOT, the cost of typical work zone ITS often is 3% to 5% of the total cost of the project [6]. Based on the survey of key practitioners and stakeholders conducted by the authors, 1% to 10% of the total cost of the project should be allocated to the deployment of ITS in work zones depending on the size, function, duration, and complexity of the project, as well as the number of work zone ITS applications. In addition, the cost varies significantly depending on the following factors:

- purchasing vs. leasing system equipment;
- temporary vs. permanent components (e.g., the ITS used for the work zone is used permanently);
- Therefore, in calculating the cost of the deployment of an ITS, the following costs must be considered:
- cost of procurement, including purchasing, renting, or other procurement approaches;
- cost of operation and maintenance;
- cost of the ITS staff, including office staff and field staff.

Table 5. Performance measures for evaluating work zone ITSs.

| Work Zone ITS | Mobility/Operational Performance Measures | User Satisfaction | Safety Performance Measures |
|---------------|-------------------------------------------|-------------------|----------------------------|
|               | Change in travel time/reliability          | •                 | •                          |
|               | % Time at Free-Flow Speed                  | •                 | •                          |
|               | Level of Service                           | •                 | •                          |
|               | Volume (Throughput)                        | •                 | •                          |
|               | Volume/Capacity Ratio                      | •                 | •                          |
|               | Queue Length                               | •                 | •                          |
|               | Diversion Rate                             | •                 | •                          |
|               | Delay per Vehicle                          | •                 | •                          |
|               | Speed                                      | •                 | •                          |

| Work Zone ITS | Performance Measures | User Satisfaction | Safety Performance Measures |
|---------------|----------------------|-------------------|----------------------------|
|               | Law Enforcement/Emergency Services Dispatch Frequency | •                 | •                          |
|               | Service Patrol dispatch frequency             | •                 | •                          |
|               | Speeding Citation Frequency                    | •                 | •                          |
|               | Crash Frequency                               | •                 | •                          |
|               | Worker Fatalities and Injuries                 | •                 | •                          |
|               | Work Zone Intrusion Frequency                  | •                 | •                          |
|               | Speed                                        | •                 | •                          |
|               | Change in travel time/reliability              | •                 | •                          |
|               | % Time at Free-Flow Speed                      | •                 | •                          |
|               | Level of Service                               | •                 | •                          |
|               | Volume (Throughput)                           | •                 | •                          |
|               | Volume/Capacity Ratio                         | •                 | •                          |
|               | Queue Length                                  | •                 | •                          |
|               | Diversion Rate                                | •                 | •                          |
|               | Delay per Vehicle                             | •                 | •                          |

| Work Zone ITS | Performance Measures | User Satisfaction | Safety Performance Measures |
|---------------|----------------------|-------------------|----------------------------|
|               | Speed Advisory System | •                 | •                          |
|               | Travel Time Estimation System                  | •                 | •                          |
|               | Construction Vehicle Warning System            | •                 | •                          |
|               | Excessive Speed Warning System                  | •                 | •                          |
|               | Hazardous Condition Warning System             | •                 | •                          |
|               | Intrusion Detection System                      | •                 | •                          |
|               | Over Dimension Warning System                   | •                 | •                          |
|               | Stopped Traffic Warning System                  | •                 | •                          |
|               | Dynamic Lane Merge System                       | •                 | •                          |
|               | Portable Signal System                          | •                 | •                          |
|               | Variable Speed Limit System                      | •                 | •                          |
|               | Temporary Ramp Metering System                  | •                 | •                          |
Table 6. Performance measure data and sources.

| Primary Goal                     | Type of Data                                      | Sources of Data                                      |
|----------------------------------|---------------------------------------------------|------------------------------------------------------|
|                                  | Mobility                                          |                                                     |
| Queue Length                     | • Sensors (vehicle presence, speed)               | • Visual Inspection (Observations at Site)           |
|                                  |                                                   | • Photo/Video                                        |
|                                  |                                                   | • Drone Video                                        |
| Travel Time/Delay                | • Pilot Vehicles                                  | • Spot Sensors (speed)                               |
|                                  | • Cameras                                         | • License-Plate Matching System                      |
|                                  | • Spot Sensors (speed)                            | • Probe Data and Third-Party Reporting               |
| Volume (Throughput)              | • Temporary Mechanical Data collection, Tube Counter|                                                     |
|                                  | • Manual Vehicle Count                            |                                                     |
|                                  | • Volume Sensors                                  |                                                     |
| Diversion Rate                   | • Spot Sensors (volume)                           | • Road Sensors (volume)                              |
|                                  | • Road Sensors (volume)                           | • Third Party Reporting                              |
|                                  | • Spot Sensors (volume)                           |                                                     |
| Crash Frequency                  | • Crash Report Information System (CRIS)          | • Law Enforcement Reports                            |
|                                  | • Traffic Management Center (TMC) Incident Reports|                                                     |
| Work Zone Intrusion Frequency    | • Incident Reports                                |                                                     |
|                                  | • Paper Forms                                     |                                                     |
|                                  | • Cameras                                         |                                                     |
|                                  | • Electronic-Fillable PDF Forms                   |                                                     |
| Safety                           | Work Zone Fatalities and Injuries                 |                                                     |
|                                  | • State Worker Compensation Commission Accident Statistics|                                        |
|                                  | • Occupational Safety & Health Administration (OSHA Reports)|                                      |
|                                  | • DOT Crash Records/Reports and Law Enforcement Reports|                          |
| Speed                            | • Spot Sensors                                    | • Spot Sensors                                       |
| Frequency of Service Patrol and Fire Department Dispatches | • Service Patrol Dispatch Logs                 | • Emergency Response Logs                           |
| Frequency of Speeding Citations  | • Law Enforcement Reports                         |                                                     |
| Customer Satisfaction            | One-on-One Interviews                             | • In Person/Telephone Interview Questions            |
|                                  | Customers’ Complaints                             | • Customers’ Complaints Database Entries             |
|                                  | Formal Customer Survey/Questionnaire              | • Survey/Questionnaire Response                      |

The Intelligent Transportation Systems Joint Program Office of the U.S. Department of Transportation maintains an online database that includes unit cost estimates for over 200 ITSs [31], but some highway agencies may have their own database. FHWA has developed a software tool, i.e., the ITS Deployment Analysis System (IDAS), which can be used to estimate the benefits and costs of more than 60 types of ITS investments [32]. The agencies can use those available tools and databases to estimate the costs of the candidates for the work zone ITS based on the specifications of the project.

At the end of Step III, the information about the benefits of each of the candidates for the work zone ITS and the estimation of the costs can help the designer to narrow down the list of candidates and select the final system(s) to be deployed in the project.
### Table 7. Non-monetary benefits of the deployment of work zone ITSs.

| Work Zone ITS | Non-Monetary Benefits |
|---------------|-----------------------|
| **Speed Advisory System** | • It reduces the lengths of queues and decreases the potential for traffic crashes in the area approaching work zones.  
• The system increases the capacity of the roadway through the work zone area. |
| **Travel Time Estimation System** | • The system improves the reliability of travel times for drivers  
• The system provides the drivers sufficient information concerning travel to calm tempers and to ease the frustration associated with travel delays. |
| **Construction Vehicle Warning System** | • The system decreases tailgating when it is activated.  
• The system avoids or reduces crashes involving haul trucks and upstream secondary crashes. |
| **Excessive Speed Warning System** | • The system alerts drivers of their entry into a portion of the work zone at a speed above the advisory speed limit.  
• It provides real-time warning to an individual driver and sufficient time to slow down for the hazardous condition. |
| **Hazardous Condition Warning System** | • The system provides real-time information to alert drivers of a possible hazard on the roadway ahead, especially at night.  
• The system also notifies construction staff of the hazardous situation so corrective measures can be taken. |
| **Intrusion Detection System** | • The system helps to reduce the risk of accidents caused as a result of an intruding vehicle by alerting drivers that they have intruded into the work space.  
• The system detects intruding vehicles and warns workers of the danger before the errant vehicle can be seen by the work crew. |
| **Over Dimension Warning System** | • The system stops drivers of oversized vehicles from entering the work zone and requires them to use an alternate route.  
• The system warns the roadway workers of an approaching oversized vehicle that may intrude into their work space. |
| **Stopped Traffic Warning System** | • The system provides information to drivers concerning stopped vehicles ahead, which allows them to use alternate routes or be prepared to stop safely.  
• The system also reduces rear-end collisions and secondary crashes. |
| **Dynamic Lane Merge System** | • The system reduces merge-related erratic maneuvers during congested periods.  
• In Dynamic Early Merge, the system gives significant warning to drivers so that they have adequate distance to merge.  
• The Dynamic Late Merge System eliminates drivers’ misunderstandings by giving them instructions on lane usage and merging points. |
| **Portable Signal System** | • The system moves traffic through two-way rural highway work zones with one lane open to traffic.  
• The system safely and efficiently eliminates flaggers from the work zone. This removes the most exposed individual in a work zone from harm’s way, saving lives, moving traffic, and reducing costs. |
| **Variable Speed Limit System** | • The system encourages drivers’ compliance with the speed limit in the work zone.  
• It reduces variations in the speeds of vehicles, which increases the capacity of the roadway and may reduce crashes within the work zone. |
| **Temporary Ramp Metering System** | • The system controls the rate at which vehicles enter the work zone from the ramp so that the downstream capacity is not exceeded.  
• The system decreases congestion due to merging ramp vehicles on the mainline and reduces the number of crashes in the work zone. |

#### 3.1.4. Step IV: Deployment and Evaluation of the ITSs

After finalizing one or more work zone ITSs, the system(s) will be considered for deployment in the project according to the related standards and guidelines. NHDOT, MnDOT, and MassDOT have prepared typical layout diagrams for work zone ITSs. Those
layout diagrams are overview representations and not detailed designs, i.e., the dimensions are not drawn to scale. Furthermore, the layout diagrams do not show the advance warning signs and other standard, temporary traffic control signs. In using those layout diagrams, engineering judgment is required to customize the system to a specific project. The designer and the contractor are responsible for ensuring that all applicable agency standards, guidelines, and practices are followed in the development and field deployment of work zone ITS plans.

Once work zone ITSs are deployed and the corresponding data (Table 6) are collected and stored, the data can be used to create performance measure reports. These reports allow the assessment of the overall operations in the work zone, and the information can be used to improve the current operations or assist with the deployment of better work zone ITSs in the future. Figure 2 shows all four steps of the framework of the guideline that were developed.

![Figure 2. Framework for the selection and deployment of ITSs in a work zone.](image)

4. Case Study

The authors selected a work zone project to apply the methodology (ITS feasibility assessment) and identify the potential ITSs for the project. The construction project was a TxDOT highway improvement project, located on the exit ramp of Interstate 10 East to Spur...
330. The scope of the project was to replace the existing jointed and asphalt concrete overlay (ACP) with continuously reinforced concrete pavement (CRCP) including grading, base, CRCP pavement, replacement of curb inlets, signing and pavement markings. The ramp included two 3.7-m lanes with 1.8 and 3 m shoulders. The length of the roadway under construction was about one kilometer, and the posted speed was 56 kph. The current and projected average daily traffic (ADT) of the roadway was 15,100 and 20,900, respectively. The project was planned to be completed in five months, and the work activities were expected to occur during both day and night. The geometry of the roadway were changed for the construction as the initial two lanes of the ramp were reduced to one lane, and the work space was protected by a barrier. The percentage of heavy vehicles traveling along the case study road was greater than 15% and the number of crashes on the segment of the road was four during three years. Figure 3 shows the layout of the project.

Figure 3. Reconstruction project of I-10 east ramp exit to Spur 330.

4.1. Feasibility Assessment

The work zone was a segment of an existing road, and the motorists were moving through the facility during the work activity. There was an existing permanent changeable message sign in advance of the work zone that could be utilized as an ITS element for the project. Assuming there would be a possible funding for the ITS deployment, the authors used the scoring criteria for the ITS feasibility assessment. After assigning the corresponding scores to each factor (Table 8), the scores added up to 45, indicating that work zone ITS(s) was likely to provide significant benefits relative to the associated costs.

4.2. Potential ITS Identification

Both safety and mobility were considered as the goals of the work zone ITS deployment for the case study. Table 4 was utilized to assess the existing/expected characteristics of the project to identify the potential ITSs appropriate for the project. Among all the project characteristics, those conditions that are related to the case study were identified along with the ITSs that could address the conditions. The ITSs applicable for each condition were indicated by the check marks in Table 9 (and similarly, “N/A” for any ITS that was not applicable for the condition). From the table, it can be seen that the following ITSs had potential to be deployed in the project:
• speed advisory system, to provide the drivers with real-time speed advisory information before reaching the ramp;
• stopped traffic warning system, alerts the drivers of a traffic slow-down or stopped traffic on the ramp;
• dynamic lane merge system, to give positive directions to motorists on lane usage and merging from two lanes to one lane.

Table 8. Work zone ITS feasibility assessment for the case study.

| Criteria | Score |
|----------|-------|
| Factor 1—Duration of construction | |
| • Longer than two years (10 points) | |
| • Longer than one year (6 points) | |
| • 6 to 12 months (4 points) | |
| • 3 to 6 months (2 points) | |
| • Less than 3 months (1 point) | 2 |
| Factor 2—Change in roadway capacity (long-term, i.e., greater than 30 days) | |
| • Loss of one travel lane in both directions (8 points) | |
| • Loss of one travel lane in either direction (6 points) | |
| • Loss of both the right and left shoulders (4 points) | |
| • Loss of the right shoulder (2 points) | |
| • Narrowed travel lanes (1 point) | 6 |
| Factor 3—Availability of alternate routes around the work zone | |
| • No alternate routes (4 points) | |
| • An alternate route with available spare capacity (2 points) | |
| • Several alternate routes with available spare capacity (0 points) | 2 |
| Factor 4—Traffic volume on the roadway | |
| • High volume, ADT ≥ 50,000 for interstates/freeways and/or >10,000 ADT for 2-lane roadways (10 points) | |
| • Intermediate volume: between 30,000 and 50,000 ADT for Interstates/Freeways and/or between 1,000 and 10,000 ADT for 2-lane roadways (5 points) | 10 |
| • Low volume: less than 30,000 ADT on interstate highways/freeways and below 1,000 ADT on 2-lane, 2-Way roadways (1 point) | |
| Factor 5—Posted speed | |
| • Greater than 100 kph (3 points) | |
| • 70 to 100 kph (2 points) | |
| • 50 to 70 kph (1 point) | |
| • Less than 50 kph (0 point) | 1 |
| Factor 6—Percentage of heavy vehicles | |
| • Greater than 15% (10 points) | |
| • 8% to 15% (5 points) | |
| • Less than 8% (1 point) | 10 |
| Factors 7 to 21—Impact of specific issues (0 to 3 points each, based on judgment) | |
| Factor 7—Insufficient sight distance | 0 |
| Factor 8—High speeds/chronic speeding | 0 |
| Factor 9—Existing crash history within the work zone project | 1 |
| Factor 10—Variability of the speed of the traffic | 3 |
| Factor 11—Unusual/unpredictable weather patterns, such as heavy rain, ice, fog, snow | 2 |
| Factor 12—Frequently changing traffic conditions | 0 |
| Factor 13—Merging conflicts and hazards where the work zone tapers | 0 |
| Factor 14—Complex traffic control layout with multiple access points (i.e., ramps or side streets) | 0 |
| Factor 15—Construction vehicle entry/exit speed differential relative to traffic | 2 |
| Factor 16—Limited offset to median or roadside barrier/guardrail | 3 |
| Factor 17—Lane diversion – use of highway crossover or center work zone | 0 |
| Factor 18—The road is an emergency route for a hospital. | 0 |
| Factor 19—The road work affects the only entrance to a neighborhood. | 0 |
| Factor 20—The construction work or a part of it is done at night. | 3 |
| Factor 21—Frequent non-peak lane closures | 0 |
| Total Score | 45 |
| Critical Project Characteristics | Work Zone ITS |
|----------------------------------|---------------|
| Temporary ramp geometry has an inadequate length of acceleration lane. | N/A N/A N/A |
| Vehicles inadvertently may follow a truck off the roadway due to the high volume of traffic or insufficient sight distance. | N/A N/A |
| A hazardous driving condition is predicted (such as flash flooding, impaired visibility due to smoke or fog, slippery or rough conditions, hazards on the roadway due to falling rocks or other debris). | N/A |
| The work zone may cause regular, recurring delays in excess of 15 min. | N/A |
| Two lanes of traffic must merge into one lane. | ✓ |
| Traffic must reduce speed to safely negotiate a hazardous condition. | ✓ N/A |
| Construction causes temporary minimal clearance for large vehicles using the roadway. | ✓ |
| A truck merge lane cannot be provided on the project or the haul road entrance is visibly obscured to drivers. | N/A N/A N/A |
| The roadway volume is above the level where the traffic must suddenly adjust speed or change lanes. | ✓ N/A |
| The location of the day’s work activities does not always require a reduction in speed. | N/A |
| Stop or slowing traffic is not expected, particularly when visibility is restricted. | ✓ |
| Traffic operations must be controlled along a two-lane, two-way highway where one lane is closed and alternating traffic movements are necessary. | N/A |
| Capacity reduction through long-term lane closures | N/A N/A ✓ ✓ N/A N/A |
| | 2 0 0 0 0 0 1 2 2 0 0 0 |
Table 6 can be used to identify the type of performance measures and the corresponding data source for evaluating the systems when installed in the field.

5. Conclusions

The primary goal of this research was to develop a selection methodology based on the identification of the specific needs of users or travelers to assist project designers in assessing whether a particular construction or maintenance project should be considered for ITS deployment in a work zone. If so, the guideline would assist in determining the work zone ITSs that would be most appropriate for the project. To achieve the goal, the researchers: (1) reviewed different ITSs and technologies that could be used in work zone projects, (2) selected the criteria (related to motorists and work zone projects) that would have to be evaluated in order to identify the eligible work zone projects for the deployment of ITSs, and (3) developed a guideline to assist project designers in selecting one or more work zone ITSs in order to be deployed in the project.

While highway work zones are a necessary part of maintaining the transportation infrastructure, they present both safety and mobility challenges. Work zones reduce the capacity of the roadway, which causes congestion and traffic delays. There is a need to find new ways to manage work zones so that traffic can move safely through them. The implementation of Work zone ITSs seeks to address these safety and mobility challenges. Using ITS in work zones can improve safety and lessen the delays that come from reduced capacity and incidents. Any expected benefits from work zone ITS depend heavily on selecting the appropriate work zone ITS and application.

Work zone ITSs may be combined for a particular project if there is no budget limitation for implementing more than one ITS. In case of budget limitation, cost–benefit analysis (Step 3 in Figure 2) will be important in order to select the best ITS. However, one limitation is the difficulty in converting the non-monetary benefits of the deployment of work zone ITSs into comparable measures for the analysis. If any permanent ITS infrastructure exists within the limits of the project, e.g., cameras, detectors, or changeable message signs, integration with this existing infrastructure should be taken into consideration as part of the design of the work zone ITS.

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