Guidance on Data Needs, Availability, and Opportunities for Work Zone Performance Measures

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16. Abstract

Current Federal Regulations (23 CFR 630 Subpart J) encourage States to collect and analyze both safety and mobility data to support the initiation and enhancement of agency-level processes and procedures addressing work zone impacts. The purpose of this guidance document is to provide practitioners with the skills to identify current data sources (both existing data and data collected specifically for the work zone) for use in work zone performance measurement, as well as potential data sources that could be useful to work zone performance measurement in the near future. This document is also intended to assist practitioners in determining how to select and compute useful work zone performance measures, given the data sources available to them. For both current and potential data sources, guidance is presented on the viability of each source for work zone performance measurement, as well as on possibly leveraging opportunities to maximize the value of data collection and extraction efforts. In addition to information about data sources and opportunities, guidance is provided regarding work zone performance measures that the various data sources can support. Where appropriate, examples are provided as to how data assessment, collection, application, and interpretation can be accomplished. In this way, document users can obtain an overall perspective.

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EXECUTIVE SUMMARY

Performance measures quantify how a particular work zone or several work zones together are affecting traveler safety and mobility. In addition, performance measures can help agencies and contractors assess if and how their work zone safety and mobility policies, processes, and procedures are working well or should be improved. In the context of highway work zones, there are three major data needs for performance measurement:

- Performance data ("how much" a work zone affects travelers, the agency, and/or contractor);
- Exposure data ("who" or "what" are being affected); and
- Work zone indicator or stratification data ("when" or "where" the effects are occurring).

With regards to how much work zones affect conditions, four categories of performance data are viewed as important:

- ***Mobility*** – data that characterize how trip duration for an individual or the number of trips being made are affected by a work zone;
- ***Safety*** – data that characterize how risks to travelers and highway workers are affected by a work zone;
- ***Customer satisfaction*** – data that characterize how travelers, residents, and business owners in or near a work zone perceives its effect on them; and
- ***Agency and contractor efficiency and productivity*** – data that can be used to assess contractor/agency efforts to minimize the duration and extent of travel impacts from a work progress perspective.

Within the mobility category, performance data can be further subdivided into the following subcategories:

- Throughput;
- Unit travel times or delay;
- Travel time reliability; and
- Traffic queues.

Likewise, the safety performance category can be further divided into the following:

- Traffic crashes;
- Operational safety surrogates; and
- Worker accidents.

Exposure data categories include:

- Counts or distances traveled through work zones by travelers or vehicles;
- Project, phase, activity durations (such as hours of work activity), or worker-hours in the field; and
- Number of phases or activities that occur.

Meanwhile, indicator or stratification data categories include:

- General roadway design characteristics (type of road, normal number of travel lanes, shoulder presence and size, speed limit, etc.) before the project began, and design characteristics of interest within the work zone (lane and shoulder widths, long-term lane closures, design characteristics of crossovers and lane shifts, etc.);
- Locations and times of work activities of interest (temporary lane closures, full road closures, etc.) and dates of major phase changes; and
- Time and characteristics of events of interest (weather events, major incidents, special events, etc.).

There are several ways practitioners may obtain data for use in work zone performance measurement. One method for accessing data is to ***extract it*** from existing sources. Another method is to specifically ***collect the data of interest*** through a variety of methods. Lastly, data may be ***interpolated or estimated*** from existing or collected data sources. For exposure and indicator or stratification data (which are used to compute many of the specific performance measures presented later in this document), it typically requires digging into project-specific files and databases, culling the desired data from them (usually by hand), and then collating and correlating these data with the performance data.

Overall, work zone performance measure selection and use involves five main steps:

- Step 1. Determine the categories of work zone performance that are of interest
- Step 2. Decide which work zones will be measured
- Step 3. Decide what work zone conditions are of most value to measure
- Step 4. Determine what data sources are available for computing performance measures at each work zone of interest, and assess their potential usefulness and limitations
- Step 5. Identify and compute specific performance measures of interest

Several sources of data exist for most of the performance measure subcategories of interest. These are identified, along with the key considerations regarding their application for work zone performance measurement, throughout this guidance document. A set of recommended performance measures that could be computed with the available data, prioritized by the expert practitioner panel assembled for this project, are also presented throughout the document.

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LIST OF ACRONYMS

AADT	Annual average daily traffic
ATR	Automatic traffic recording
AVI	Automatic vehicle identification
AVL	Automatic vehicle location
BLS	Bureau of Labor Statistics
DMS	Dynamic message signs
FAST	Freeway and Arterial System for Transportation (Las Vegas)
FHWA	Federal Highway Administration
GIS	Geographic information system
HCM	Highway Capacity Manual
HOT	High occupancy toll
HOV	High occupancy vehicle
IRB	Institutional Review Board
ITS	Intelligent transportation system
MOT	Maintenance-of-traffic
OSHA	Occupational Safety and Health Administration
PDO	Property-damage-only
SSAM	Safety Surrogate Assessment Model
TMP	Transportation management plan
TOC	Traffic operations center
TT	Travel time
TTC	Time-to-collision
VMT	Vehicle-miles-travelled

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1.0 INTRODUCTION

1.1 Why Are Work Zone Performance Measures Needed?

Public-sector agencies and private-sector companies need to understand how well they are designing and operating work zones in order to improve the efficiency and effectiveness of the work zones. They must determine whether any changes made to improve current and future work zones are having the desired effect. The selection, development, and use of performance measures are critical to this improvement effort.

The effect of highway work zones on traveler safety and mobility has become an increasingly important focus area for the Federal Highway Administration (FHWA) in recent years. Current Federal Regulations (23 CFR 630 Subpart J) encourage states to collect and analyze work zone safety and mobility data. The data is to be used to support the initiation and enhancement of agency-level processes and procedures to avoid or mitigate work zone impacts.

Performance measures quantify how a particular work zone or several work zones together are affecting traveler safety and mobility. In addition, performance measures can help agencies and contractors assess if and how their work zone safety and mobility policies, processes, and procedures are working well or should be improved.

> The New York State Department of Transportation score the specific traffic control and safety attributes of the work zones it inspects each year, and uses those scores to identify key topics or issues to emphasize in future department work zone training efforts (*1*).

The challenges related to measuring performance for many agencies and companies include:

1) Identifying which measures are most important;
2) Determining what data is needed for the measures;
3) Determining where and how to get the data; and
4) Determining how to compute the desired measures from the collected data.

Agencies and companies must also consider the availability, accessibility, and applicability of data when deciding which work zone performance measures to focus on and how the measures will be computed and reported. These challenges and decisions can be somewhat daunting. This guidance document has been prepared to assist agencies and companies in developing useful and effective work zone performance measures.

1.2 What Data Is Needed?

In the context of highway work zones, there are three major data needs:

- Performance data;
- Exposure data; and
- Work zone indicator or stratification data.

An overview of the types of data needed is provided in Table 1-1. In essence, ***Performance data*** describe "how much" a work zone or group of work zones affects travelers, the agency, and/or the contractor. Performance data includes travel times that motorists using the work zone experience relative to their normal travel times, traffic crashes or worker accidents, and public opinions gathered about driving conditions through a work zone.

Table 1-1. Overview of Data Types

Type	Description	Examples
Performance data **(How much did the work zone affect things?)**	Data that may be used by an agency, contractor, or other entity (i.e., the public) to evaluate something about work zone operations or its effects.	• Travel time changes • Crash increases • Driver opinions about travel conditions
Exposure data **(Who or what was affected by the work zone?)**	Data used – in combination with performance data – to normalize to a rate of some type (i.e., per vehicle, per trip, per hour).	• Vehicles-miles passing through the work zone, for the entire day or for some subset of the day (i.e., during the peak periods) • Hours of temporary lane closures occurring during the project • Total worker-hours occurring over a project or project phase • Number of person-trips passing through the work zone, for the entire day or some subset of the day
Indicator or stratification data **(When or where did the effects occur?)**	Data used to further stratify or focus the performance data to a particular subset of the work zone or work operation, such as: • during peak travel hours, • during certain specific work tasks, • during particular project phases, or • for work zones with specific features of interest.	• Time periods when temporary lane closures occurred • The specific hours selected as the AM or PM peak period • Specific dates when a project was in a particular construction phase

Meanwhile, ***exposure data*** count the "who" or "what" that are affected by the work zone or group of work zones of interest. Most commonly, exposure is measured in terms of number of vehicles, people, and/or miles of travel through the work zone. The number or total hours of lane closures or full roadway closures required during a project is another example of exposure data. In fact, the number of work zones that experience a particular condition (such as a traffic queue that exceeds a particular length) could also be considered a type of exposure data for assessing levels of compliance with an agency's work zone mobility goals or policies.

Finally, work zone ***indicator or stratification data*** focus attention or otherwise target how performance was affected during specific activities, phases, time periods, or other events of the work zone. For example, an agency may be interested in determining whether its current lane closure restriction policy is keeping delays below a selected threshold. In this case, times and locations of lane closures would be indicator data needed to focus on those delays occurring when and where lane closures were in place. Indicator/stratification data might also be used in determining the appropriate exposure data of interest, such as the dates when a project was in a particular phase. Knowing those specific dates, an agency could then use crash data and vehicle-miles-traveled (VMT) through the work zone data to compute a crash rate per VMT during that particular phase.

Overall, the three data types in Table 1-1 are extremely broad and general, and further categorizations within each type are necessary in order to fully assess and understand the current and potential sources for such data and the opportunities to use the data for work zone performance measurement. Key categories of work zone performance, exposure, and indicator or stratification data addressed in this document are shown in Table 1-2. These categories were verified through Delphi survey techniques, using an expert panel of practitioners assembled for this document development, as being both important and useful to many different audiences with possible interest in work zone performance.

With regards to how much work zones affect conditions, four categories of performance data are viewed as important:

- ***Mobility*** – data that characterize how trip duration for an individual or the number of trips being made are affected by a work zone;
- ***Safety*** – data that characterize how risks to travelers and highway workers are affected by a work zone;
- ***Customer satisfaction*** – data that characterize how travelers, residents, and business owners in or near a work zone perceives its effect on them; and
- ***Agency and contractor efficiency and productivity*** – data that can be used to assess contractor/agency efforts to minimize the duration and extent of travel impacts from a work progress perspective.

Within these main categories, subcategories also exist. As an example, within the mobility category, performance data can be further subdivided into the following subcategories:

- Throughput;
- Unit travel times or delay;
- Travel time reliability; and
- Traffic queues.

Table 1-2. Work Zone Performance Data Categories

<table>
<tr><th>Type</th><th>Categories</th><th>Subcategories</th></tr>
<tr><td rowspan="4">Performance Data</td><td>Mobility</td><td>• Throughput
• Unit travel time
• Delays
• Travel time reliability
• Queues</td></tr>
<tr><td>Safety</td><td>• Crashes
• Safety surrogates
• Worker accidents</td></tr>
<tr><td>Customer satisfaction</td><td>• Project-specific satisfaction
• Agency or region-wide satisfaction with work zones</td></tr>
<tr><td>Agency and contractor productivity and efficiency</td><td>• Construction productivity
• Roadway durability</td></tr>
<tr><td rowspan="3">Exposure Data</td><td>Traveler/vehicle counts and travel distances</td><td rowspan="3">N/A</td></tr>
<tr><td>Durations of specific work tasks or conditions, worker-hours in the field</td></tr>
<tr><td>Work zone activities/conditions</td></tr>
<tr><td rowspan="3">Indicator or Stratification Data</td><td>Roadway classification/conditions</td><td rowspan="3">N/A</td></tr>
<tr><td>Work zone activity/conditions</td></tr>
<tr><td>Events (incidents, special events, weather, etc.)</td></tr>
</table>

Likewise, the safety performance category can be further divided into the following:

- Traffic crashes;
- Operational safety surrogates; and
- Worker accidents.

As Table 1-2 illustrates, the exposure data and work zone indicator or stratification data include multiple categories. Exposure data categories include:

- Counts or distances traveled through work zones by travelers or vehicles;
- Project, phase, activity durations (such as hours of work activity), or worker-hours in the field; and
- Number of phases or activities that occur.

Meanwhile, indicator or stratification data categories include:

- General roadway design characteristics (type of road, normal number of travel lanes, shoulder presence and size, speed limit, etc.) before the project began, and design characteristics of interest within the work zone (lane and shoulder widths, long-term lane closures, design characteristics of crossovers and lane shifts, etc.);
- Locations and times of work activities of interest (temporary lane closures, full road closures, etc.) and dates of major phase changes; and
- Time and characteristics of events of interest (weather events, major incidents, special events, etc.).

The event data can be used to eliminate data with external influences (such as crashes occurring after a major incident created significant backups in the work zone), or may be used to further examine impacts that occurred during those events (such as how crashes in the work zone were affected when adverse weather conditions were present).

1.3 Where Can Practitioners Obtain Data?

Methods for Obtaining Data

1. Extract from existing sources
2. Collect using electronic or manual methods
3. Interpolate or estimate from existing or collected data sources

There are several ways practitioners may obtain data for use in work zone performance measurement. One method for accessing data is to ***extract it*** from existing sources. For example, when evaluating queue lengths in work zones, practitioners may use data from existing Traffic Operations Center (TOC) spot speed traffic sensors. Another method is to specifically ***collect the data of interest*** through a variety of methods. In the case of queue lengths, this may entail manual on-site observations by field personnel, closed-circuit TV operated by TOC staff, or via temporary video cameras. Lastly, data may be ***interpolated or estimated*** from existing or collected data sources. For example, a practitioner may decide to estimate traveler delays from manually-recorded queue length data, using basic macroscopic traffic flow relationships (an illustration of how to do this can be found in the chapter on mobility data and performance measures).

The potential sources of performance data are described in detail in later chapters of this document. For exposure and indicator or stratification data (which are used to compute many of the specific performance measures presented later in this document), it typically requires digging into project-specific files and databases, culling the desired data from them (usually by hand), and then collating and correlating these data with the performance data. Table 1-3 presents the various exposure and indicator/stratification data categories listed in Table 1-2, and identifies the common source or sources where that data may be obtained. Vehicle and person-based exposure data can come from the same sources as throughput data (one of the mobility-related performance measure categories) and is discussed in more detail in chapter 3. For the other data categories, project-related files are the main source of information available. Presently, details about the status of each work zone on a day-by-day basis are commonly limited to whatever is captured in the daily diaries kept for each project. A few agencies transfer these diary entries into their overall construction management database, but still as a narrative summary of activities. Project engineers or inspectors are those most commonly assigned to this task, as are maintenance supervisors for crews performing various minor maintenance tasks with agency forces.

Table 1-3. Sources of Exposure and Indicator/Stratification Data

Exposure and Indicator/Stratification Data Categories	Potential Data Sources
Traveler/vehicle counts and travel distances	• See discussion on work zone throughput in the mobility-related performance measures chapter (starting on page 3-1)
Durations of specific work tasks or conditions	• Project daily diary notes • Electronic construction management database • Agency maintenance activity records • Lane closure notification/approval database
Work zone activities/conditions	• Project daily diary notes • Electronic construction management database • Project plans (for maintenance-of-traffic conditions in each phase, temporary geometrics) • Agency maintenance activity records • Lane closure notification/approval database
Roadway classification/conditions	• Roadway inventory file or database
Events (incidents, special events, weather, etc.)	• Transportation operations center (TOC) operator incident logs • Project daily diary notes • Electronic construction management database entries • National Climatic Data Center (www.ncdc.noaa.gov)

Traditionally, there can be considerable variation in both the quality and quantity of information pertaining to work activities documented in the project diary or project correspondence files, depending on who does the documentation. As agencies and contractors become more involved in work zone performance measurement, emphasis on documentation of details that are of most interest will likely be required. Long-term lane and shoulder reductions will typically be documented in the maintenance-of-traffic (MOT) sheets of a set of project plans, but the actual dates that the reductions begin and end will not. Similarly, any changes in the MOT plan itself will need to be captured (both when and what) in the diary narrative. For short-term or short-duration lane or shoulder closures, documentation of the time, location, and extent of closures (how many lanes are closed or kept open) will often only be found in project diary information. A few agencies may have procedures in place to receive notification of these temporary lane closures (or perhaps to even approve them). In regions with TOCs, lane closure notifications to the TOC may also be an information source. For these agencies, this database can be a potential source of the desired exposure and indicator/stratification data, although the prevalence of "phantom" lane closures (those that have been requested and approved but which do not end up actually occurring) should be assessed before relying on this database for this purpose.

Document Objectives

Provide practitioners with the skills to:

1. Identify current data sources for work zone performance measurements
2. Identify potential data sources for work zone performance measurement that may be available in the near future
3. Select and compute useful work zone performance measures, given the data sources that are available

Agencies will usually have a fairly good database of roadway conditions that exist normally on the facilities under its jurisdiction. These data can be easily accessed to establish baseline conditions regarding geometrics, access, etc. for comparison against conditions implemented through and around the work zone. For specific events that may compound with the effects of the work zone, common data sources include incident logs (for work zones located within the coverage of a transportation management center), unusual events documented in the project diary, and historical weather data from the National Climatic Data Center.

1.4 Guidance Document Objectives

The purpose of this guidance document is to provide practitioners with the skills to identify current data sources (both existing data and data collected specifically for the work zone) for use in work zone performance measurement, as well as potential data sources that could be useful to work zone performance measurement in the near future. This document is also intended to assist practitioners in determining how to select and compute useful work zone performance measures, given the data sources available to them.

For both current and potential data sources, guidance is presented on the viability of each source for work zone performance measurement, as well as on possibly leveraging opportunities to maximize the value of data collection and extraction efforts. This leveraging can occur by identifying multiple ways in which a particular data source can be used for performance measures and for other purposes, such as for operating a work zone intelligent transportation system (ITS) for traveler information that can also provide data for work zone performance measures. Leveraging can also occur when certain data are used for multiple work zone performance measures. For example, an agency may choose to monitor work zone queues because of both work zone mobility and safety performance concerns.

Work Zone Performance Measure Guidance Provided

1. Priorities identified by an expert practitioner panel
2. Basic computations required
3. Appropriate audience(s) for the measures
4. Impact of different data sources on measures that are computed

In addition to information about data sources and opportunities, guidance is provided regarding work zone performance measures that the various data sources can support. The measures have been prioritized by an expert practitioners panel using an on-line Delphi surveying technique (details on how the measures were prioritized is included in Appendix A). Information is provided regarding the basic computations needed for each measure, its overall level of importance (as rated by the panel), and the audiences for which the measure would be most applicable. A discussion of how specific measures compare when computed using different data sources is also provided. Where appropriate, examples are provided as to how data assessment, collection, application, and interpretation can be accomplished. In this way, document users can obtain an overall perspective.

2.0 SELECTING USEFUL PERFORMANCE MEASURES

Points to Remember

- Measures should allow for monitoring of agency or company goals and targets
- Use only as many measures as needed
- Both project-level and aggregated measures can be important

Performance measures can be valuable tools for both public agencies and private-sector companies. However, it is important to select and use measures that can actually help improve work zone processes and procedures, can be understood by others who might be shown the measures, and can be determined within the data availability constraints that exist. Collecting data and computing measures, by itself, does not automatically lead to better results; the measures must align with what the agency or company deems important. At the same time, performance measurement choices cannot be made without regard to the type and amount of data that can be obtained and used to compute the measures. Thus, the decision as to what performance measures will be monitored should not be made lightly.

2.1 Characteristics of Useful and Effective Work Zone Performance Measures

Effective Performance Measure Characteristics

- Capable of showing progress in meeting goals
- Useful for making decisions on how to improve processes and procedures
- Can provide clear feedback on results of improvement actions
- Are clear and easy to understand
- Provide both accurate and precise indications of conditions

Ideally, work zone performance measures should have the following five characteristics:

Measures should show progress being made toward achieving desired results or goals – Measures that easily convey whether or not the agency or company is meeting or progressing towards its goals or targets (such as an agency's work zone safety or mobility policy statements) will keep improvement efforts focused on those targets.

Measures should aid in making improvement decisions – In addition to tracking progress towards ultimate goals or targets, measures that relate to or imply possible courses of action for improvement are desirable. Measures without a purpose are undesirable.

Measures should provide clear feedback on the results of improvements or courses of actions that have been implemented – Similarly, measures that are sensitive enough to track whether improvement decisions have or have not achieved their intent help agencies and companies adjust and revise those decisions more quickly and efficiently.

Measures should be clear and easy to understand – One of the important uses of performance measures is to easily convey a “snapshot” of how an agency or company is doing and (hopefully) improving. Measures that are highly complex or which require significant technical background to understand, have more limited use than those which are inherently easy to understand. Also, most agencies will desire both project-level and program-level (aggregated across multiple projects) measures.

Measures need to be both accurate and precise – Performance measure accuracy defines how closely it can capture the “true” condition or improvement being measured; performance measure precision pertains to the level of confidence one can place on the performance measure value itself.

2.2 Users of Work Zone Performance Measures

Depending on how they are disseminated, work zone performance measures may be of interest to- and used by the following audiences:

- Practitioners responsible for designing the MOT plans for work zone projects, as well as other types of programmatic uses (such as establishing and revising work zone policies and procedures);
- Practitioners responsible for the day-to-day traffic safety and operations through the work zones; and
- The traveling public.

Work zone design practitioners are constantly tasked with striking a balance between providing space for traffic to use and providing space for work crews to complete the required project tasks. Often, certain less-than-optimum design features must be allowed on a temporary basis (e.g., narrowed lanes, temporary loss of shoulders, lane shifts) in order to accommodate the work tasks. The actual effects of these decisions are of interest to designers for consideration in future project designs.

Once a work zone has been established, practitioners responsible for its day-to-day operation desire constant feedback on both the safety and mobility effects in order to detect and correct any problems that may exist. Many work zones are very dynamic, involving multiple phases with different traffic-handling schemes, and a range of work activities that can affect traffic. These dynamics make it particularly challenging to detect when problems exist.

Finally, work zone travelers themselves desire information about work zone conditions and performance, particularly mobility performance. The value of real-time traveler information to motorists has long been recognized. Measures that reflect expected changes to normal travel conditions and which can be used as a surrogate of future conditions can aid in both departure time and route choice decisions. Measures reflecting the safety record through a project (i.e., number of injury or fatal crashes occurring in a work zone) can be useful as a reminder to motorists to drive safely and defensively.

2.3 Determining Work Zone Performance Measures of Greatest Interest and Use

As suggested above, the value and usefulness of a particular work zone performance measure will depend in part on the audience(s) for which it is intended.

- In general, the ***traveling public*** will be most interested in real-time (and forecasted) project-level, or if multiple projects exist along a particular route, corridor-level measures of the effects of work zones upon mobility and, perhaps, traffic and pedestrian safety.
- ***Practitioners with day-to-day work zone operational responsibilities*** will also be interested in real-time safety and mobility performance as well as in customer satisfaction, or perhaps more accurately, lack of satisfaction.
- Finally, ***practitioners who design work zones*** will be interested in how their design decisions ultimately affect safety, mobility, customer satisfaction, and the productivity and effectiveness of the work tasks that have to be accomplished.

Differences exist, within each audience group, of the level of detail required for various measures **–** While it is true that the types of measures of greatest interest will vary by audience, there will be differences in the level of detail desired in the various measures for certain subsets of those audiences. For example, travelers and higher-level manager practitioners responsible for overall operations in a given corridor may only be interested in the aggregated, corridor-level effect of all work zones upon peak-period travel times. Meanwhile, practitioners responsible for a given project may only be interested in how the project is impacting travel times during the peak periods, and may also be interested in how travel times are affected when lanes are temporarily closed for short-term work activities.

The level of performance measure aggregation or disaggregation needed can affect the amount and type of data needed to generate those measures **–** For certain measures, such as the number of work zone fatalities occurring during a year, aggregation across all work zones is important to allow an agency to assess its level of compliance with, or progress towards, its overall work zone safety goal. In other cases, the effect of a single work zone may be of greatest importance, such as the increase in peak period travel times during a specific phase of a complex project. The data needs for both types of performance measures are obviously much different.

Determining which work zone performance measures will be used also requires consideration of the data required to compute them. Ideally, an agency or company would simply identify the desired set of measures and the data necessary to develop those measures would be readily available. In reality, data availability must be considered as part of performance measure selection. As will be discussed later in this document, several data sources can be used for work zone performance measurement, if they are available to the practitioner, and more importantly, are appropriate for the conditions being monitored and measured.

Ultimately, work zone performance measures should be an integral part of an agency's or company's continuous improvement process to reduce work zone impacts. An example of how this could occur is presented in Figure 2-1. An agency establishes a work zone mobility or safety policy goal (perhaps no more than a 20 percent increase in crashes in a work zone relative to pre-work zone conditions). The agency should periodically assess what percent of its projects are meeting that goal. Those projects that did not meet the goal could then be examined in greater detail to help the agency understand the possible causes for the failure to meet the goal. In turn, this better understanding of causes could lead to improvements in either the design or operational procedures that the agency establishes for future projects.

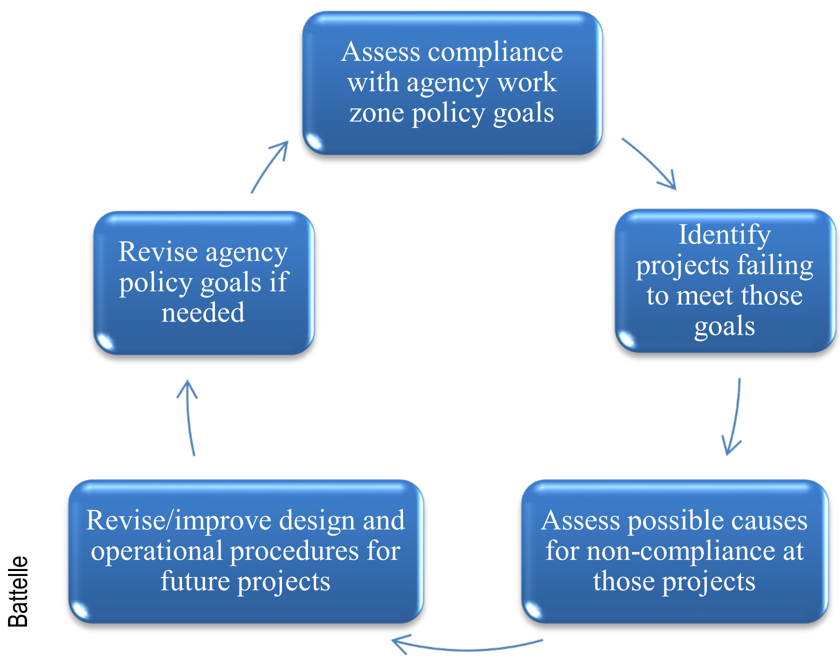

Figure 2-1. Example Use of Performance Measures for Continuous Improvement of Agency Work Zone Policy

Overall, work zone performance measure selection and use involves five main steps:

Step 1. Determine the categories of work zone performance that are of interest – An agency or contractor must initially decide which of the basic categories of possible work zone performance data and measures are of interest. In determining these categories, practitioners should consider both the work zone mobility policies and goals or targets already established, and the possible data sources available for the agency or contractor to use.

Step 2. Decide which work zones will be measured – Most agencies need not measure every work zone. A sampling of work zones, focusing on those of most interest to the agency, can actually be more useful from a continuous improvement process because it makes data collection, analysis, and interpretation more manageable. It should be noted that the same work zones need not be used for all performance measures. Rather, an agency or company may monitor some work zones because of concerns for their mobility impacts, monitor the safety impacts of several other work zones where certain crash countermeasures were implemented for testing, and monitor still other work zones located in a sensitive area in a downtown area for business and customer satisfaction, for example.

Step 3. Decide what work zone conditions are of most value to measure – Work zones are often complex, involving multiple phases and a wide range of work activities at different locations that vary in terms of their effects on traffic. Identifying which phases, locations, and work activities are of interest is needed to determine what performance measures are most appropriate. Measures may be computed for the entire project, for certain phases, or for during work tasks. In addition, these decisions can influence what data is needed to compute those measures. In some cases, data availability (or lack thereof) may require a change in either which work zones will be measured, or possibly a change in the categories of performance data of interest.

Step 4. Determine what data sources are available for computing performance measures at each work zone of interest, and assess their potential usefulness and limitations – Depending on the location of the work zone and the types of measures of interest, data that can be used to generate the measures may already exist within the agency. If not, one or more of several possible data collection methods may be employed. Opportunities may exist to leverage data collection efforts to meet multiple performance measure needs. Trade-offs between data accuracy/precision and costs to obtain must also be assessed.

Step 5. Identify and compute specific performance measures of interest – Once data that can be used for performance measurement have been located or collected, the final step is to identify the specific measures of interest, and then compute the measures. For most performance categories, measures can be defined to characterize the entire project (i.e., total number of hours when a traffic queue was present), specific times of interest (increase in average delay per vehicle during the peak hours), or for certain phases or work activities (average maximum queue length during hours when temporary lane closures were in place). Consideration must be given to the level of accuracy and precision attainable with the data when interpreting the results from a specific work zone as well as for an aggregated set of work zones.

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3.0 DATA SOURCES AND COMPUTATIONAL METHODS FOR MOBILITY-RELATED PERFORMANCE MEASURES

Considerable attention has been given in recent years to the mobility impacts of work zones upon travelers, business owners, and nearby residents. Many state work zone policies in place around the country have specific limitations on the allowable amount of delay that work zones may cause. Some agencies also limit the hours during which lanes can be closed on certain roadways so as to reduce or eliminate the potential for queues and delays to be created.

Work zone performance has multiple mobility-related dimensions. Specifically, mobility impacts are commonly described and monitored in terms of the following categories:

- Throughput;
- Delays;
- Unit travel times (i.e., minutes per mile traveled, which can also be expressed as an average travel speed over the length of the roadway segment);
- Travel time reliability; and
- Traffic queues.

A number of data sources are available to assess these mobility impacts. In some cases, data that already exists within an agency or is gathered as part of other agency requirements can be used; in other cases, data must be collected in and around the work zone in order to measure mobility impacts. A discussion of these various sources is presented in the following sections.

3.1 Mobility-Related Data Sources

3.1.1 Throughput Data

Data pertaining to the number of vehicles (or, in some cases, people) that pass through a work zone, overall and as a rate per unit time, are useful to practitioners in assessing the adequacy of design decisions pertaining to the work zone MOT and the overall transportation management plan (TMP). Such data also represents vehicle/person exposure to the work zone that is then used in normalizing other types of data and performance measures. Traffic throughput is dependent upon traffic demand attempting to pass through the work zone, as depicted in Figure 3-1. If the work zone capacity is adequate to service traffic demands at all times throughout the day, then traffic demand volumes and throughput will be the same. However, if the work zone capacity is not sufficient to meet the traffic demand during certain times of the day, throughput per unit time will be equal to work zone capacity rather than traffic demand volumes. These conditions are characterized by congested traffic flows and traffic queues, and often result in significant traffic diversion away from the work zone during those congested periods. For these reasons, it is generally necessary to collect count data at work zones that experience overcapacity conditions if accurate throughput measures during the congested periods are desired.

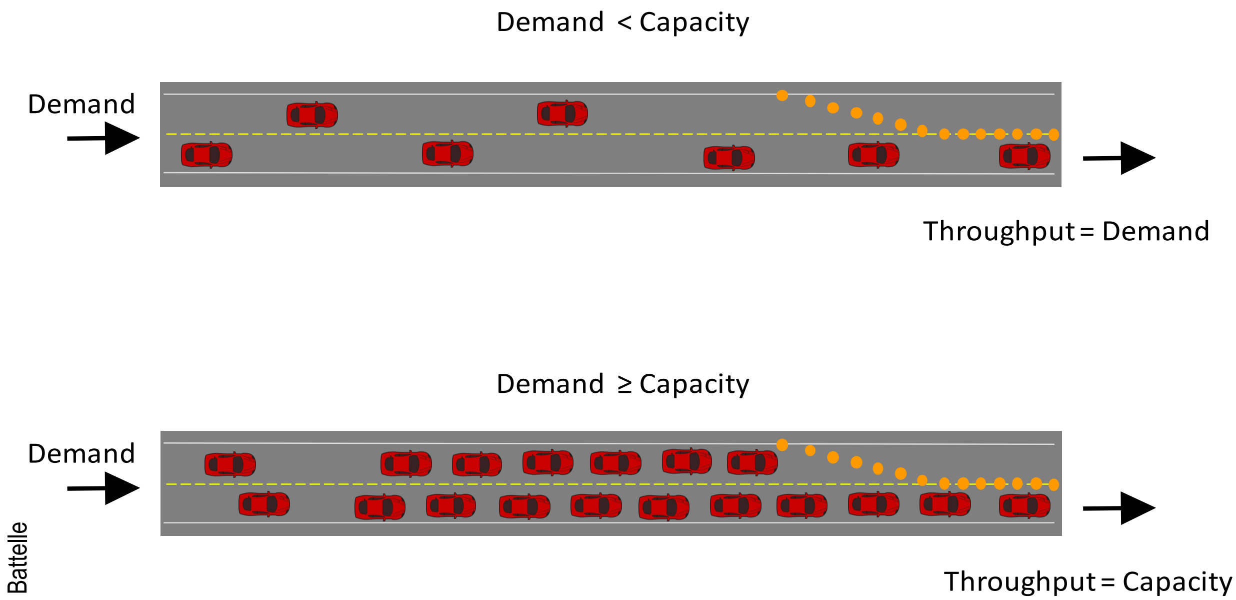

Figure 3-1. Relationship between Traffic Demand and Throughput at Work Zones

Of course, if throughput is measured continuously over the entire duration of congestion build up and dissipation each day, cumulative throughput will be equal to cumulative demand volumes. It is important to keep in mind that traffic volumes during particular portions of a day (nighttime, AM or PM peak periods, etc.) can vary significantly from day to day, due to a variety of reasons. For purposes of work zone performance measurement, it is therefore beneficial to use an average from several days of data for throughput measures (normally, at least three days of data are desirable) to establish the "typical" volumes during the time period(s) of interest.

Work zone throughput measures should be based on data from multiple days

3.1.1.1 Data Sources That Already Exist

Throughput Data That May be Available from Existing Agency Sources

- TOC or traffic signal system vehicle count data
- Toll facility usage data
- Automatic traffic recording (ATR) station data
- Planning and programming AADT estimates

Data already existing within an agency – A number of sources of work zone throughput data exist within most agencies. In many metropolitan areas, for example, tremendous amounts of detailed traffic volume data collected by TOCs can be accessed for work zone throughput. Work zones that occur within the limits of TOC coverage need only to identify which traffic sensors are of interest for which dates and times, and request the data from the TOC operations personnel. Likewise, vehicle count data can be accessed from some arterial street signal systems for work zone throughput.

Toll facility operators likewise have a ready source of throughput data available to them in the form of usage data. Because of the need or desire to continue to collect revenue, it is likely that interruption of the power supply will be less of a concern for toll facility work zone data. It should be noted, though, that project work may involve the loss of power within the work zone limits, rendering traffic sensors unusable unless steps are taken ahead of time to ensure power to them is maintained.


TTI

Figure 3-2. Some Traffic Signal Systems can be a Source of Traffic Volume Data

For those work zones located outside of the limits of TOC coverage or on toll facilities, agencies also collect significant amounts of traffic volume data to support their own programming and planning efforts, and to comply with federal reporting requirements about vehicle travel in its jurisdiction. Most agencies have deployed permanent automatic traffic recording (ATR) stations at strategic locations on key roadways. For work zones located immediately upstream or downstream of these stations, it is usually a simple manner to request count data for the dates of interest (during the work zone, and if significant diversion is expected, before and/or after the work zone as well). As mentioned above, it will be important to determine whether the data reflects capacity-constrained throughput or traffic demand volumes. More importantly, some agencies have algorithms built into their data systems to check for "irregularities" in the ATR data. A work zone that significantly reduces traffic flows over the ATR sensor could trigger an "irregularity" alarm and be replaced in the dataset with an expected value for that time period. Consequently, it is important to check to ensure that the volumes taken from an ATR location are indeed the actual counts during the days of interest.

Verify that ATR volume data obtained for work zone performance measurement purposes are the "true" counts obtained and not an expected value generated by the system.

In many cases, even an ATR station is not conveniently located near the work zone of interest. If data cannot be specifically collected for the work zone (as discussed below), practitioners are limited to the availability of annual average daily traffic (AADT) estimates that the planning and programming division may have available for the various roadway links within the system. While these are not actual counts,

AADT estimates on a roadway can be used to approximate throughput (and vehicle exposure) if it can reasonably be assumed that traffic demands never exceeded work zone capacity, and no other reasons existed to cause significant diversion away from the project.

they can be useful for estimating work zone throughput when 1) it is believed that demand volumes will not exceed the capacity of the work zone, 2) it is believed that little or no diversion from the work zone will occur, and 3) estimates of throughput are desired for purposes of computing vehicular or traveler exposure levels through the work zone. If estimates other than 24-hour exposure are desired, such as traffic exposure during peak periods or during short-term lane closure activities, it will be necessary to apply an estimated time-of-day volume distribution (usually obtained from ATR station data for similar roadway types) to extract the throughput values for the time periods of interest.

Throughput Data Collected Specifically For a Work Zone

- Work zone ITS deployment data
- Temporary mechanical data collection device data
- Manual vehicle count data of work zone throughput at key times and locations

Data collected specifically for a work zone – If existing sources of work zone throughput are not sufficient for performance measurement purposes (because of large amounts of expected diversion or significant periods of congestion developing due to reduced work zone capacity, for example), practitioners will need to obtain data specifically collected for the work zone.

If a work zone ITS has been deployed to help manage traffic and provide real-time driver information, data from that system can be used for performance measurement provided that arrangements have been made ahead of time for archiving the data and making it accessible for analysis in the desired format. Practitioners can also develop a sampling plan to collect throughput data during key phases or at key times of the day. Such a plan should include repeated measurements on separate days to increase the robustness of the values obtained (a minimum of three measurements should be targeted).

TTI

Figure 3-3. Mechanical Counters can Sample Throughput and/or Demand Volumes at a Work Zone

Data samples can be obtained through various mechanical means (e.g., pneumatic tube counters, in-lane devices, portable video camera recordings) or can be done manually. It should be noted that mechanical counters and manual counters may not be very practical for data collection on high-volume, high-speed roadways.

Sources of Person Throughput Data

- Manual sampling of per-vehicle occupancy levels
- Manual or video collection of pedestrian throughput

Person throughput data – Although vehicle throughput measures will normally be obtained, some work zones may be better measured on a per-person basis, if demand management strategies that encourage transit ridership, increased vehicle occupancy (i.e., high occupancy vehicle [HOV] or high occupancy toll [HOT] lanes), or green travel modes (walking, biking) are a component of a project's TMP. Consequently, urban work zones that impact pedestrian travel may also necessitate person volume data collection and analysis.

The New Jersey Department of Transportation identifies bicycle and pedestrian traffic as key evaluation measures (both within the project and on alternative routes) as part of its work zone traffic mitigation guidelines (2).

Typical person count sources include:

- Manual sampling of vehicle occupancy through the work zone; and
- Counts (manual or electronic) of pedestrian throughput.

The vehicle occupancy rate determined through sampling is then multiplied by vehicle throughput to determine person throughput in the work zone.

3.1.1.2 Potential Sources in the Near Future

Connected Vehicle Initiative – The national connected vehicle initiative now under development by multiple federal and state agencies as well as private-sector vehicle manufacturers and other partners may offer potential for gathering work zone throughput data. Work is underway to establish general architectures, communication protocols, and other standards upon which a connected vehicle system will operate. To be useful, sufficient market penetration of this technology will first need to occur so that reasonable estimates of throughput can be made based on the data provided by the various connected vehicles that pass through the work zone.

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Figure 3-4. The Connected Vehicle Initiative involves Communication between Vehicles and between Vehicles and Roadside Infrastructure

3.1.1.3 Key Considerations and Trade-offs of Throughput Data Sources

Table 3-1 presents a tabular summary outlining the key considerations and trade-offs associated with the various throughput data sources currently available. As noted previously, the location of the data relative to the work zone is a key consideration regardless of the data source used. Checking any ATR data to ensure that they are the "true" volumes and not modified because of an errant assumption about a sensor problem is another key consideration.

Table 3-1. Considerations and Trade-offs of Throughput Data Sources

Data Source	Key Considerations and Trade-offs
All data types	• Location of data relative to the work zone dictates whether data is demand volumes or work zone throughput • Data from multiple days are desirable to reduce effects of day-to-day variations in traffic flow
TOC or signal system vehicle count data, toll facility usage data	• Important to verify that data will be available once work has started (no loss of power to sensors)
ATR station data	• Need to verify that data are "true" counts and not adjusted
Agency AADT estimates	• AADT values will provide reasonable estimates of throughput and exposure when work zone capacity is not exceeded at any time during the day • If diversion occurs, AADT estimates will overestimate throughput and exposure
Work Zone ITS data	• Important to verify that data will be archived and made available for performance measurement computations
Throughput data collection via mechanical counters or manual counts	• Collection with certain types of mechanical counters (pneumatic tubes) are usually not practical for high-volume, high-speed roadways • Manual counts are labor intensive
Manual collection of vehicle occupancy levels	• Useful at work zones where efforts to encourage shift to green travel and HOV travel are part of the work zone TMP
Manual or electronic collection of pedestrian throughput	• Useful at work zones where efforts to encourage shift to green travel and high-occupancy vehicle travel are part of the work zone transportation management plan • Hours of peak pedestrian travel may not always coincide with hours of peak vehicle travel
Connected vehicle data	• Date of availability still uncertain

3.1.2 Delay, Unit Travel Time, and Travel Time Reliability Data

Travel time delay, unit travel times, and travel time reliability can all describe work zone effects upon traveler mobility. ***Delay*** is perhaps the most common data category used in assessing work zone mobility impacts, and is defined as the difference between the actual travel time through the work zone and the travel time it normally takes to make the trip at that time of the day. In urban areas where trip origins and destinations are complex, some agencies find it preferable to discuss mobility effects in terms of ***unit travel times*** (i.e., minutes of travel per mile or other roadway length). Meanwhile, ***travel time reliability*** refers to the day-to-day fluctuations in trip times on a facility that a motorist must add to their expected trip time in order to ensure an on-time arrival.

Shoulder closures and other temporary geometric restrictions in work zones can increase the effects of traffic incidents on travel times, thereby increasing the unreliability of travel times through the work zone. Similar to unit travel times, travel time reliability generally has more applicability to work zones on high-volume roadways in urban areas.

3.1.2.1 Data Sources Currently Available

Delay, Unit Travel Time, and Travel Time Reliability Data That May be Available from Existing Agency Sources

- TOC spot speed sensor data
- TOC tracking of vehicles through use of cameras
- TOC point-to-point travel time data using AVI, AVL, or license-plate recognition technology

Data from existing agency sources – Sources that measure speeds at spot locations and interpolate between locations to approximate travel times over segments are common nationally. Most TOCs are now estimating travel times using data from their spot speed sensors and posting them on dynamic message signs (DMS). In general terms, use of spot speed sensor data to estimate travel times is less accurate than point-to-point travel time measures, especially when the roadway segment is congested. However, speed sensors will detect delays more quickly than point-to-point travel time measurement methods.

TOC staff can also estimate travel times through the use of its camera surveillance system. Knowing the locations of the cameras and the distance between them, TOC operators can identify a unique vehicle in one camera view (a large truck, an automobile with a company logo on the side, etc.), record the time, pull up the next camera view downstream, wait until that same vehicle comes into view, and record that time. Subtracting the two times will then yield the elapsed travel time between the two cameras. This approach has been successfully used by personnel in the Freeway and Arterial System for Transportation (FAST) operations center in Las Vegas, NV.

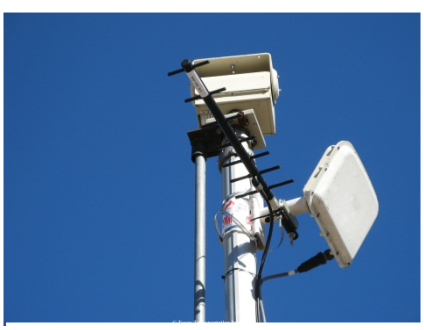

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Figure 3-5. Delays can be Estimated from a Series of Spot Speed Sensors along the Roadway Segment

Travel times and delays through a work zone are most directly determined from point-to-point travel time measurements. Historically, point-to-point travel time data was obtainable only through more costly technologies such as automatic vehicle identification (AVI), automatic vehicle location (AVL), or license plate recognition systems. Regions with significant toll road presence will generally have enough AVI transponder coverage to allow for reasonably accurate point-to-point travel time data to be obtained. In addition, it should be noted that data collected in this manner reflect recent, rather than, current conditions.

For example, point-to-point travel time data that indicates delays of 30 minutes actually refers to trips that were initiated more than 30 minutes ago, not necessarily trips that are being initiated or entering a roadway segment of interest at the present time.

Delay, Unit Travel Time, and Travel Time Reliability Data Collected Specifically for a Work Zone

- Data extracted from a work zone ITS deployment
- Deployment of portable point-to-point travel time data collection devices
- Manual spot speed sampling using radar or lidar devices
- Manual collection of travel times by driving through the work zone repeatedly
- Estimation of travel time delays from manually-collected queue length data

Data collected specifically for a work zone – Work zones located outside the boundaries of an operating TOC must rely on temporary data collection efforts. A variety of technical options are available. A work zone ITS deployment can often provide speed or travel time data, especially if the system is deployed to provide real-time traveler information. Care must be taken to ensure that such data is archived and made available for performance measurement analysis.

The Arizona Department of Transportation used a license plate recognition system through a work zone on State Route 68 to monitor the contractor's compliance with a travel time delay incentive/disincentive clause in the contract (*4*).

Conceptually, portable data collection systems could be developed for any type of point-to-point travel time data collection technology. Such a technology could be attached to any of a number of portable traffic data collection trailers in use as part of existing work zone ITS and easily integrated into the data streaming capabilities of those units. Currently, a number of work zone ITS vendors are working on the integration of Bluetooth antenna into their data collection and processing capabilities (see next section on potential sources).

A number of lower-cost manual data collection approaches can also be used to obtain travel time data in work zones. Data collectors can utilize hand-held radar or lidar devices to obtain spot speeds at one or more locations along a work zone. These data may be sufficient for estimating travel time or delay if the location of work zone congestion is fairly short. Data collection personnel can also drive through the work zone multiple times and record the elapsed time it takes to complete each pass. This approach is most appropriate when conditions on the roadway were free flow prior to the work zone being deployed so that "normal" travel times can be assumed (free flow speed divided by travel distance). If not, travel time data prior to the implementation of the work zone will be needed as well. Because they are labor intensive, both of these techniques are more appropriate when they are used to target specific periods (i.e., peak hour travel time) or certain work tasks. These techniques are also more feasible when used over shorter roadway segments. For situations where field personnel cannot obtain travel times by driving through the work zone, but can occasionally document how long a traffic queue extends upstream of the work zone, it is possible to estimate delay using basic traffic flow relationships. Again, for this approach to apply, conditions prior to the implementation of the work zone must be approximately free-flow (i.e., all delays that occur can be assigned to the presence of the work zone).

To estimate how the documented queues result in travel time delays, it is assumed that both the queue itself and the work zone result in slower speeds for some travel distance. As depicted in Figure 3-6, if a queue has formed upstream of the work zone (at the lane closure bottleneck), it is realistic to assume that the flow rate through the work zone is at or near capacity, such that the speed at capacity flow can be assumed to govern through the work zone. For simplicity, an assumption of a linear relationship between speeds and density would suggest that the capacity flow speed would be one-half of the free-flow speed on the facility. Upstream of the work zone, the queue that develops would be flowing at a speed less than the capacity flow speed. Again using a simple linear speed-density relationship, the following equation (presented in Figure 3-6) produces an estimate of the average speed in queue as a function of the normal roadway capacity and the capacity expected through the work zone.

The capacity of the work zone can be estimated using procedures in the *Highway Capacity Manual* (HCM) (*5*). The HCM also provides procedures to estimate the normal traffic-carrying capacity of the roadway segment as a function of the free-flow speed on the facility. Assuming that these speeds are maintained, on average, through the entire length of the queue and work zone documented, estimates of average delays per vehicle through the queue can be computed as a function of the length of queue. Some threshold (most likely the desired speed or the posted work zone speed limit [U_{WZSL}]) would serve as the basis against which the longer travel times through the queue would be computed. This queue delay would then be added to the delay that would be generated as vehicles pass through the remainder of the work zone at capacity flow speeds (30-35 mph):

$$\frac{Delay}{Vehicle} = L_q\left(\frac{1}{u_q} - \frac{1}{U_{WZSL}}\right) + L_{wz}\left(\frac{1}{\frac{u_f}{2}} - \frac{1}{U_{WZSL}}\right)$$

Once the average delay per vehicle is estimated for each time interval that a queue is noted on the documentation form, the total vehicle-hours of delay is computed simply by multiplying the normal hourly volume by these average delay values. If the begin and end times of the lane closure and queue do not occur exactly on the hour, extrapolation techniques should be used to estimate the delays during that portion of an hour.

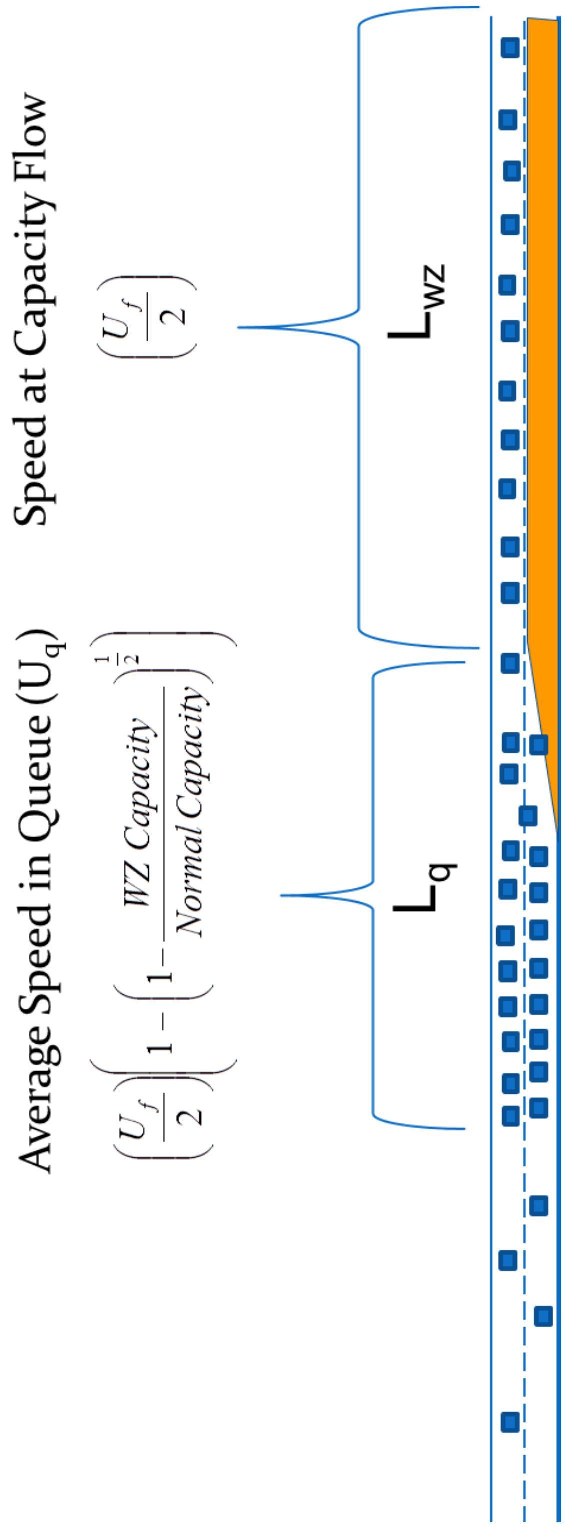

Figure 3-6. Components of Work Zone Delay

Ullman, G.L. T.J. Lomax, and T. Scriba. A Primer on Work Zone Safety and Mobility Performance Measurement. Report No. FHWA HOP-11-033. FHWA, U.S. Department of Transportation, Washington, DC. September 2011. Accessible at http://ops.fhwa.dot.gov/wz/resources/publications/fhwahop11033/fhwahop11033.pdf.

3.1.2.2 Potential Sources in the Near Future

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Figure 3-7. Bluetooth Detection Technology is a Low-cost Method of Collecting Anonymous Point-to-Point Travel Time Data

Point-to-Point Travel Times by Bluetooth Address Matching – Most mobile electronics, and many vehicles themselves, are now enabled with Bluetooth technology to allow them to connect and communicate directly with other devices. Recent advances in Bluetooth signal detection technology and address matching capabilities has made it possible to track Bluetooth devices as a low cost way to obtain point-to-point travel time. Multiple address-matching protocols are now available, and ITS vendors are working on both permanent and portable deployment solutions of this technology. Advantages of Bluetooth technology are its privacy (the device wireless addresses are all that is tracked, so user information is kept private) and its relatively low cost. Like other point-to-point travel time collection technologies, however, the data represent recently completed trips rather than current trips underway. Thus, the delays being measured through the Bluetooth system will lag those actually being experienced by those currently entering the work zone.

> The Indiana Department of Transportation has used anonymous matching of Bluetooth devices in vehicles to track point-to-point travel times in work zones (*6*).

> The Virginia Department of Transportation examined the potential of obtaining historical private-sector traffic data for the purposes of computing work zone performance metrics (*7*).

Private (3rd Party) Sources of Travel Time and Speed Data – Private-sector traffic information companies collect traffic speed and travel time data from various sources, fuse that data together, and then sell that information to various users to power various real-time travel information systems. Some agencies have now started to enter into agreements to obtain that data on routes they do not have instrumented in exchange for financial compensation and/or for data the agency already is collecting. These data will also be usable for the purposes of work zone performance measurement. In fact, some agencies have found that they can obtain such data after-the-fact for very little compensation (the main value of the data to these companies is in its real-time traveler information applications). To be useful, the data mapping protocols used by the private-sector companies (these are known as traffic message channel location codes) must be translated to mapping protocols used by the agency or contractor (such as mile point or reference markers). In addition, agencies and contractors must determine whether it will be possible to obtain data from individual days (currently, at least one private-sector company provides data averaged by time-of-day and day-of-week on a month-by-month basis).

Connected Vehicle Initiative – Although connected vehicle data may eventually be useful for estimates of work zone throughput, it is likely to be more valuable sooner as a source of data for travel times and delays. As noted previously, work is underway to establish general architectures, communication protocols, and other standards upon which a connected vehicle system will operate. Presently, protocols and standards as to how vehicles will communicate with each other (i.e., vehicle-to-vehicle or V2V) is farther along than standards as to how vehicles will communicate with roadside devices (i.e., vehicle-to-infrastructure or V2I) that will be needed before agencies will be able to easily access data for work zone performance measurement purposes.

3.1.2.3 Key Considerations and Trade-offs of Delay, Unit Travel Time, and Travel Time Reliability Data Sources

Table 3-2 presents a tabular summary outlining the key considerations and trade-offs associated with the various throughput data sources currently available. Regardless of the technology or manual procedures used, it is important to have the limits of the travel time measurement extend upstream and downstream of the work zone to ensure all of the potential impacts are fully encapsulated. It is also important to keep in mind the differences between travel times measured through spot speed sensors and point-to-point travel time estimates.

Table 3-2. Considerations and Trade-offs of Delay, Unit Travel Time, and Travel Time Reliability Data Sources

Data Source	Key Considerations and Trade-offs
TOC spot speed sensor data	• Travel time estimates tend to be less accurate when congestion is present • Important to verify that data will be available once work has started (no loss of power to sensors)
TOC point-to-point travel time data	• Important to verify that data will be available once work has started (no loss of power to sensors) • Accuracy depends on the level of market penetration of tracking technology used (AVI, AVL) • Represents recently completed, rather than current, trip times.
Work zone ITS data	• Important to verify that data will be archived and made available for performance measurement computations
Portable point-to-point travel time data collection	• Accuracy depends on the level of market penetration of devices being detected and tracked • Represents recently completed, rather than current, trip times.
Manual spot-speed data	• Labor intensive • Most useful if work zone impacts occur in a fairly small section • Most useful for assessing short time periods
Manual travel time data collection by driving through the work zone	• Labor intensive • Most useful for long work zones • Most useful for assessing short time periods • Multiple trips through the work zone increases accuracy and precision of travel time estimates
3rd party (private-sector) travel time and speed data	• Level of detail available may vary by vendor • Requires translation of data mapping protocols to agency/contractor system in order to assess work zone impacts
Bluetooth data	• Accuracy depends on the level of market penetration of Bluetooth devices in the traffic stream • Represents recently completed, rather than current, trip times.
Connected vehicle data	• Date of availability still uncertain

3.1.3 Traffic Queue Data

The last type of work zone mobility-related performance data available to agencies and contractors are traffic queue data. Whereas some agencies have established work zone mobility policies and goals based on travel delays, others have based policies on the avoidance and limitation of queues. As would be expected, individual vehicle delays and queue lengths are highly correlated. However, traffic queues are also a safety concern, due to the high speed differentials that commonly exist between traffic approaching a queue and traffic already in queue. Consequently, emphasis on monitoring the occurrence of extent of queuing at a work zone is a higher priority for some agencies.

To fully characterize queues at a work zone, both the duration of queuing and its length over time need to be obtained. Traffic queues are the storage of vehicles when traffic demand exceeds the work zone capacity (maximum throughput). Queue lengths can change dramatically over time as demand volumes change and/or large numbers of drivers divert to alternative routes.

3.1.3.1 Sources Currently Available

Queue Data Collected Specifically for a Work Zone

- Speed data extracted from a work zone ITS deployment
- Manual observation and documentation of queues from a permanent or work zone TOC
- Manual observation and documentation of queues by field personnel at the work zone

Data collected specifically for a work zone – Very few agency data sources exist or are normally collected which can also be used to measure and document traffic queues. If the work zone is located within the limits of TOC sensor coverage, spot speed traffic sensors can be used to approximate queue lengths. Thus, the accuracy of the estimation process depends on the spacing of the spot speed sensors, and the existence of detectors beyond the upstream end of the queue. The process to estimate queue lengths and durations from spot sensor data consists of four basic steps, as shown in Figure 3-8 (*8*):

Ullman, G.L. T.J. Lomax, and T. Scriba. A Primer on Work Zone Safety and Mobility Performance Measurement. Report No. FHWA HOP-11-033. FHWA, U.S. Department of Transportation, Washington, DC. September 2011. Accessible at http://ops.fhwa.dot.gov/wz/resources/publications/fhwahop11033/fhwahop11033.pdf

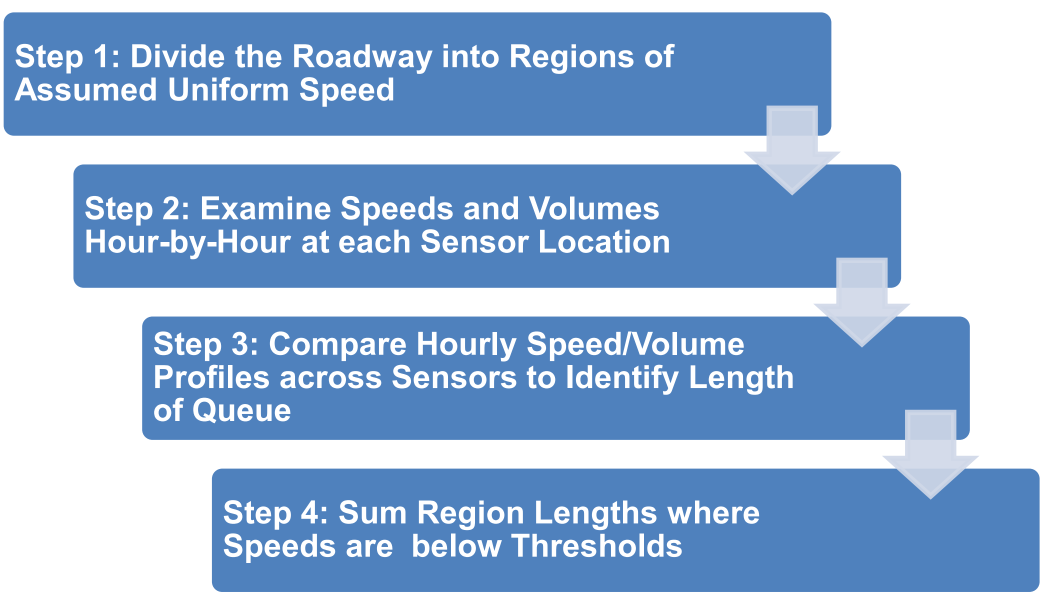
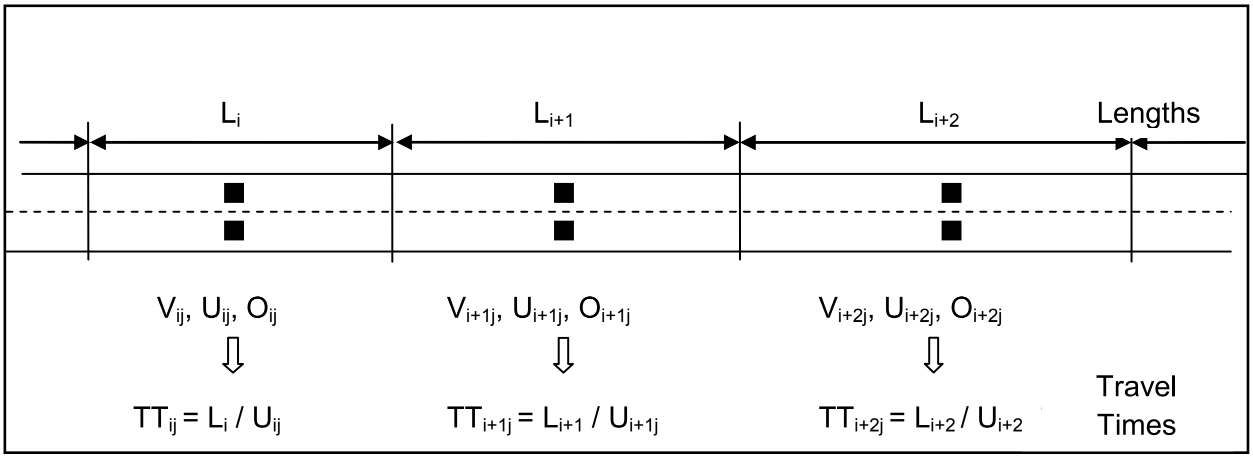


Figure 3-8. Steps to Estimate Queue Lengths from Spot Speed Sensor Data

Step 1: Divide the Roadway into Regions of Assumed Uniform Speed – In step 1, the roadway section where a work zone exists is divided into a series of segments of various lengths (L), with conditions in each segment assumed to be represented by its corresponding spot sensor data of volumes (V), average speeds (U), and detector occupancies (O) as illustrated below. Within each segment length, the travel time (TT) is estimated as the segment length divided by the average speed.



Step 2: Examine Speeds and Volumes Hour-by-Hour at each Sensor Location – To approximate queue lengths from spot sensors, the speeds at each sensor are examined in sequence and over time to identify the regions and times at each region in which speeds drop below a selected threshold. Speeds at successive sensor locations are examined together, and the length L_i for each segment below the speed threshold is added together for each time interval of interest. In the example on the next page, spot traffic sensors are located 0.2 mile, 0.8 mile, and 1.3 miles upstream of the temporary lane closure. Project diary information indicates that a lane closure began at 9:00 AM and ended at 3:30 PM.

Step 3: Compare Hourly Speeds across Sensors to Identify Extent of Queue Propagation – Starting with the downstream region, the average speeds over time at each region are examined in sequence moving upstream to estimate the upstream end of the queue each hour (as shown in Figure 3-9). For each hour (or other analysis period preferred by the agency), the objective is to identify how far upstream the queue has propagated. To accomplish this, the agency should select a speed threshold it will use to define the difference between normal traffic flow and traffic flow in a queue. This threshold can be defined as part of the agency's work zone policy or procedures in absolute terms (e.g., speeds below 10 miles per hour, or speeds less than one-half of the free-flow speed of traffic on a facility), or in terms of the amount of reduction in speed observed by traffic approaching the work zone.

G.L. Ullman, R.J. Porter, and G.J. Karkee. *Monitoring Work Zone Safety and Mobility Impacts in Texas. Research Report FHWA/TX-09/0-5571-1.* Texas Transportation Institute, College Station, TX, September 2008.

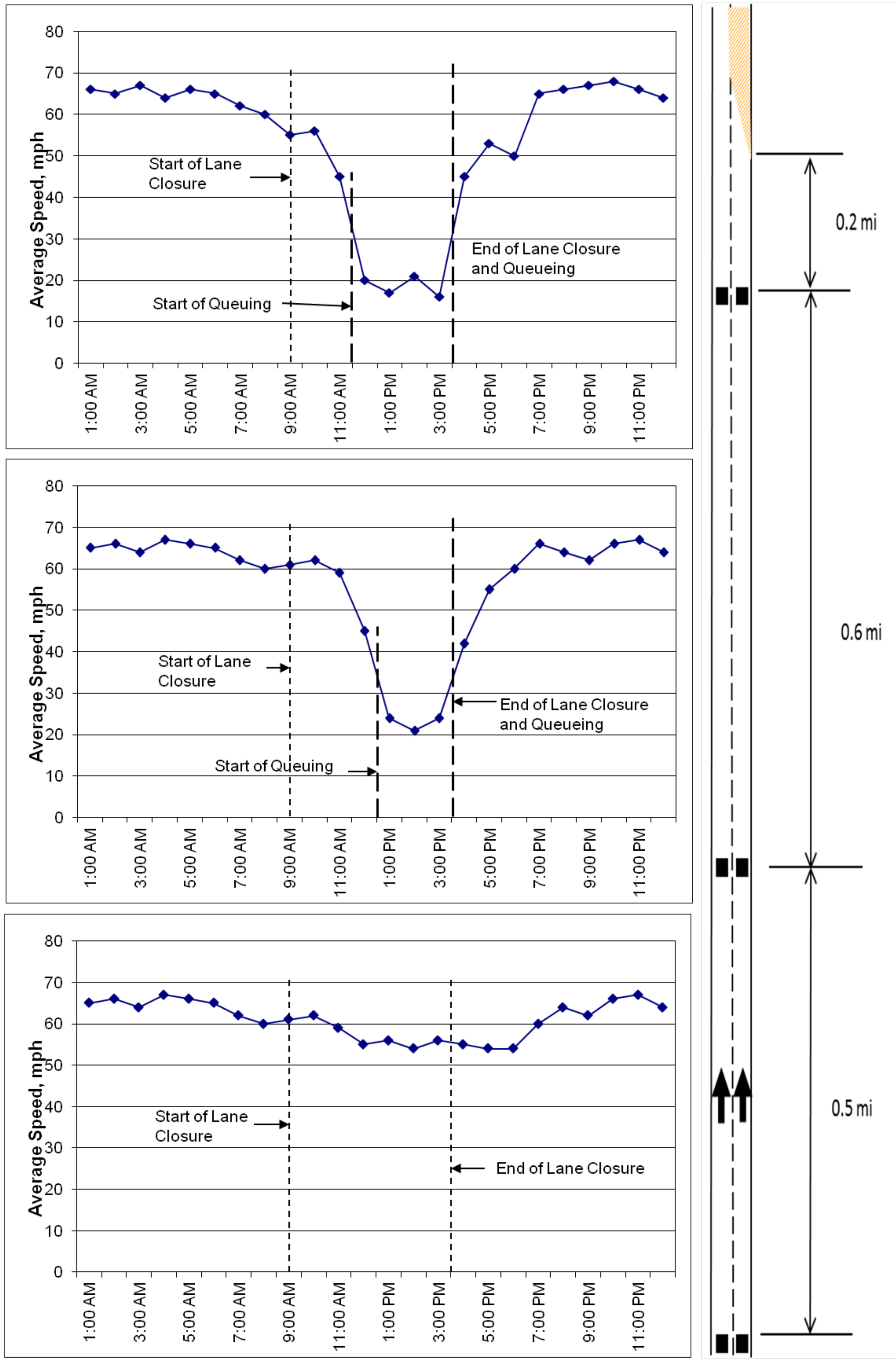


Figure 3-9. Example of Sensor Speed Analysis to Determine Duration and Length of Queue

Once a threshold is selected, it is a fairly simple task to determine the two regions in sequence that have a normal, high average speed at the upstream region and a low, congested speed indicative of the presence of queuing. The midpoint between the spot sensors of those two regions is where it is assumed that the upstream end of the queue is positioned during that hour. Performing this analysis hour-by-hour will result in a queue length profile over time at the work zone.

Step 4: Sum Region Lengths Where Speeds are Below the Threshold – To determine queue lengths for the above example, a 40 mph speed threshold was selected as indicating queued traffic conditions. Consequently, the analysis of speeds at the upstream sensor locations indicates that a queue began to develop at approximately 11:30 AM at the first sensor, which grew upstream and reduced speeds at the second sensor at about 12:30 PM. The queue did not extend back to the third sensor, since speeds never dropped below 40 mph at that location during the hours of work activity. The estimated queue length each hour is shown in Table 3-3 below:

Table 3-3. Estimated Queue Length Each Hour

Time	Estimated Location of Upstream End of Queue	Estimated Queue Length
11:00 am	None	0
12:00 pm	Between Sensors #1 and #2	0.2 + (0.6/2) = 0.5 mile
1:00 pm	Between Sensors #2 and #3	0.2 + 0.6 + (0.5/2) = 1.05 mile
2:00 pm	Between Sensors #2 and #3	1.05 mile
3:00 pm	Between Sensors #2 and #3	1.05 mile
4:00 pm	None	0

This approach will also work for data obtained from a work zone ITS deployment that uses spot speed sensors.

If TOC or work zone spot speed sensor data are not available for a work zone of interest, an agency or contractor must rely on manual techniques to obtain traffic queue data. Some TOCs and work zone ITS deployments, particularly those that exist primarily for incident identification and response purposes, do not offer full traffic sensor coverage of their system.

TTI

Figure 3-10. TOC Operators can Manually Record Upstream End of Queue Periodically for Use in Computing Queue Lengths and Durations

Rather, as shown in Figure 3-10, operators in the control room constantly scan cameras located throughout the system looking for stalled vehicles, crashes, or other operational problems. Such systems can be used to gather queue length data for work zones located within camera coverage. Operators must be trained to visually track the start of queue formation, identify key landmarks that can be used to estimate the upstream queue location on a regular basis over the duration of the queue, and document when the queue dissipates. This may require access to and use of multiple cameras if the queue propagates several miles upstream of the work zone. As an alternative, it may be possible for programmers at the TOC to write a script to capture snapshots of the camera views of interest at specific intervals, for post-event analysis of queues.

The Michigan Department of Transportation has established a manual data collection and recording process delays and queues at projects selected for monitoring that do not have electronic surveillance in place (*1*).

Another possible manual technique is for field personnel at the project site to record the queues observed. If the queue does not grow significantly and the upstream end can be seen from the work space, a field inspector or temporary traffic control technician can document it from the roadside. If the queue grows beyond view from the work space, staff may have to travel upstream in a vehicle to locate the upstream end. Continuous passes through the queue and the work zone could also be performed, each time identifying the upstream end of the queue and the beginning of the lane closure or work space that is serving as the bottleneck and thus represents the downstream end of the queue. However it is accomplished, the goal is still to document:

- The time when queuing begins;
- The length of the queue at regular intervals; and
- The time when queuing ends.

3.1.3.2 Potential Sources in the Near Future

Computer Screenshot Captures from 3rd Party Traveler Information Providers – Many private-sector traveler information providers provide website access to current travel conditions in a map format. Typically, color coding on the various routes is used to denote travel speeds on each roadway segment for which it has data. Colors generally range from green (for normal or good travel speeds) to red or black (for stopped or nearly stopped traffic). These maps most likely have a slight time lag to them (the amount of that lag is not known for certain and is not typically advertised by the providers themselves), but can provide a reasonable snapshot of travel conditions on a facility. As shown in Figure 3-11, there are software programs which can "capture" the image on a computer screen and store it in one of several possible file formats. Currently, someone with some computer science background could write a simple script to activate this screen capture software on a regular basis (such as every 15 minutes) and save the equivalent of a time-lapse series of queuing that occurs at a work zone over time. In the near future, it is possible that a time-lapse snapshot feature could be added to these software applications to accomplish the same task. Staff could then use the screen capture images to estimate when the queuing started, how long the queue was at each point in time (scaling off the images), and when the queue dissipated. One challenge with using this approach will be in determining the appropriate map resolution level for the computer screen to capture the images. If the resolution is in too close to the work zone, the queue may grow out beyond the limits of the image. If the resolution is too far out, it will be difficult to accurately estimate the length of the queue at that snapshot in time.

Google traffic map captured with the Snagit screen capture software tool

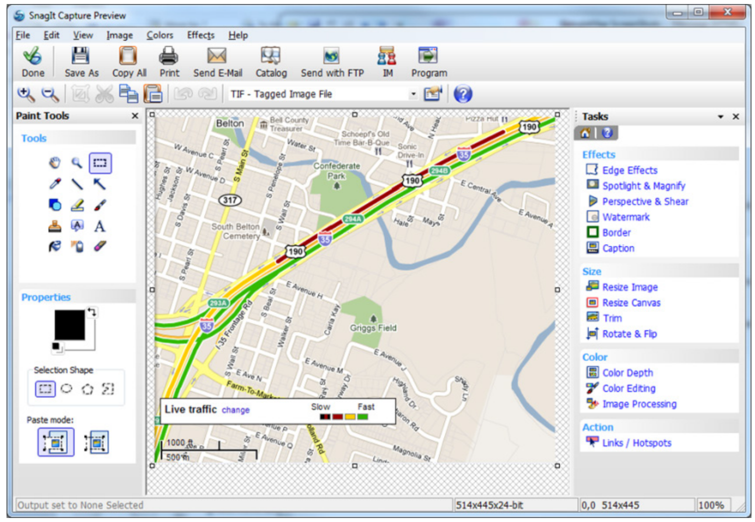


Figure 3-11. Periodic Screen Captures of Private-Sector Traveler Information Maps can also be Used to Gather Work Zone Queuing Data

Private (3rd Party) Sources of Travel Time and Speed Data – Similar to the use of these data for work zone travel time and delay data, 3rd party sources of data can also be used for assessment of traffic queues at work zones. The overall approach can be identical to that outlined above for using spot sensors from a transportation management center or a work zone ITS deployment. Issues regarding the resolution between roadway segments as defined by the vendor and segments defined by the DOT will still exist, as will the need to get to individual day data for work zones where temporary lane closures cause only occasional queues.

Connected Vehicle Initiative – Detailed information about current vehicle speed is one of the key data elements planned for this initiative. Along with the current position of each vehicle, this data stream may eventually provide detailed queue location information by identifying specific vehicle locations at which speeds decrease below a defined threshold. Algorithms will be needed to collate the speed behavior of multiple vehicles to determine where the queue is said to "begin" at any point in time.

3.1.3.3 Key Considerations and Trade-offs of Traffic Queue Data Sources

Table 3-4 provides a summary of key considerations and trade-offs that exist with the existing and potential sources of traffic queue data for work zone performance measurement. Many of these considerations are similar to those documented under the travel time, delay, and travel time reliability data sources. Manual data collection techniques (by TOC operators or by field personnel) will need the buy-in and support of agency or contractor administration, as it will impact staff ability to accomplish other assigned tasks.

Table 3-4. Considerations and Trade-offs of Traffic Queue Data Sources

Data Source	Key Considerations and Trade-offs
All data types	• Important to define what constitutes a queue to the agency or contractor (usually a minimum speed threshold) • Both queue duration (start and end times) and length over time are important data
Transportation management center or work zone ITS deployment data using spot speed sensors	• Requires detailed analysis of speeds over time on a sensor by sensor basis • Important to verify that data will be available once work has started (no loss of power to sensors)
Use of TOC cameras and operators to visually identify and document queues	• Requires adequate camera coverage upstream of work zone • Useful to develop data collection protocols regarding landmarks to use to document upstream queue position, frequency of documentation, etc.
Collection of queue data by field personnel	• Training regarding data collection protocols to follow (how often, how accurate, etc.) is important • May require personnel to travel upstream to locate queue • Needs agency or contractor administration support to ensure field personnel understand its importance
Computer screenshot captures of real-time traffic condition maps	• Setting of appropriate screen resolution size required for each work zone (based on maximum queue lengths anticipated • Time-lapse capabilities do not currently exist in most screen capture software.
Use of 3rd party traveler information data	• Level of detail available may vary by vendor • Requires translation of data mapping protocols to agency/contractor system to assess work zone impacts
Connected vehicle data	• Date of availability still uncertain

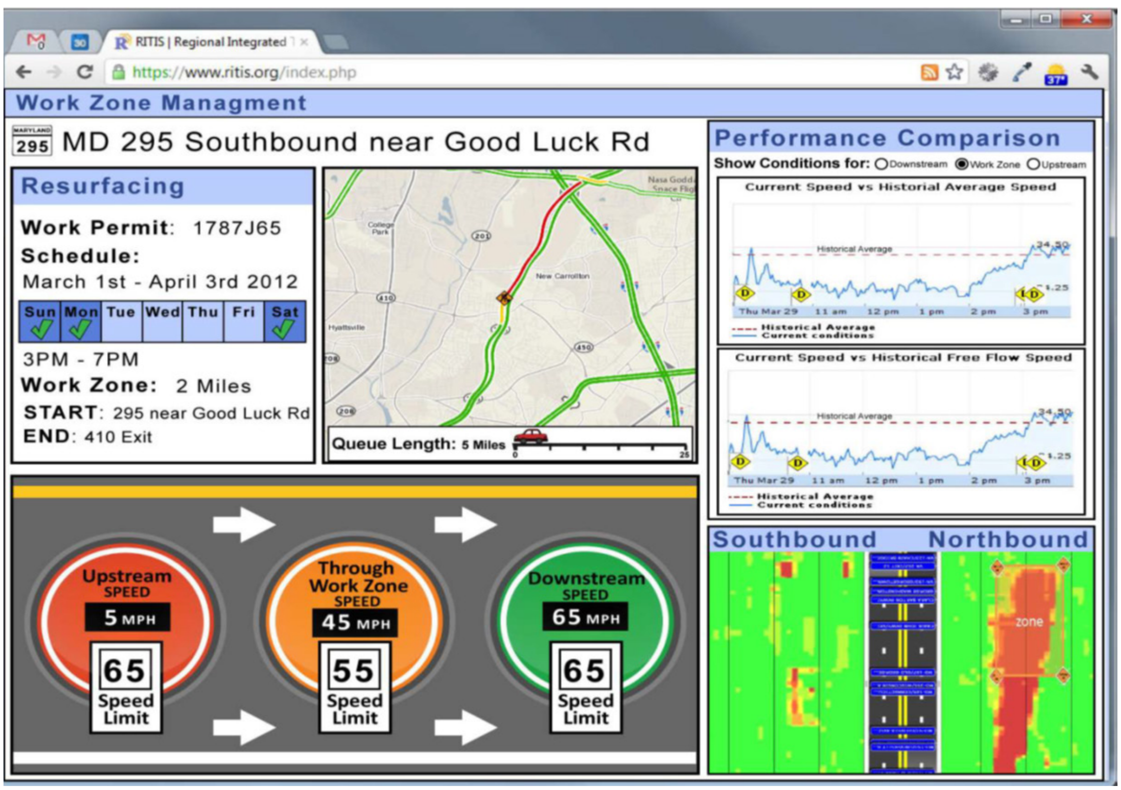
3.2 Identifying and Computing Specific Mobility Measures of Interest

3.2.1 General Considerations

Once a determination of what work zone mobility-related data are or will be available, the final task is to determine what specific measures of performance are of interest to the agency, contractor, traveling public, etc. As noted previously, agency or contractor goals, policies, and/or concerns related to mobility will also influence the number and type of measures that will be of interest. The corresponding performance, exposure, and indicator/stratification data are then gathered and collated as necessary to compute those measures.

To a large extent, the choice of appropriate measures depends on the MOT approach of each individual work zone, which in turn will depend on the roadway and traffic characteristics where the work is to be performed. Work zones where the MOT approach involves long-term closures of one or more travel lanes may suggest that measures pertaining to peak period traffic operations are of main importance. Conversely, work zones that use temporary lane closures during off-peak periods as the primary MOT approach would benefit more from a measure that targets mobility during the hours of those temporary lane closures than during peak hours. In many cases, the overall project will involve multiple phases in which different MOT approaches may be used in those different phases.

Regardless of the specific MOT approach used, in almost all cases, the main interest in the mobility performance measures will be in terms of how conditions during the work zone changed relative to the pre-work zone (or normal) conditions on that roadway segment. In locations where volumes are relatively low and operating conditions are good most of the time, any mobility impacts that are computed (increased travel times, presence of traffic queues, etc.) will be easily attributed to the work zone. In locations where traffic conditions are degraded already during peak periods or other times of the day, the additional delays or queues above those normally occurring will be of main interest. This can further affect the choice of performance measures that are to be computed. In some jurisdictions with TOCs, efforts are underway to develop simple-to-use computer dashboards that can provide current traffic conditions in and around a work zone (see Figure 3-12).



Paracha, J. Work Zone Performance Measurement using Probe Data.
Presentation of Maryland Work Zone Performance Measurement Project

Figure 3-12. Example of a Work Zone Mobility Dashboard Under Development

Each jurisdiction will have to make its own decisions as to the performance measures it chooses to track. The following sections should be used as a guide as to the types of mobility-related work zone performance measures that should be considered by an agency or contractor, and not as a comprehensive list of all acceptable measures.

3.2.2 Specific Throughput Measures

Table 3-5 presents a summary of possible throughput-related performance measures. Computational requirements of each measure, and its relative rating of importance by a panel of practitioners, are provided. Also presented in the table is an assessment of possible audiences or user groups for that measure.

Two of the measures in the table pertain to changes in throughput that occur relative to the throughput occurring before the work zone was deployed. These reductions can reflect either a reduced capacity through the work zone (relative to pre-work zone conditions), reduced demand volumes due to driver diversion to other routes or modes, or a combination of both. Some agencies and contractors emphasize the minimization of mobility impacts during hours when a work zone is inactive (hence, the specification of that particular measure).

3.2.3 Specific Unit Travel Time and Delay Measures

A number of possible performance measures pertaining to unit travel times and delays occurring in a work zone or series of work zones are provided in Table 3-6. Unit travel times, either along a corridor with multiple work zones, or through an individual work zone, can be computed fairly simply using any of the travel time data sources listed previously. These metrics are best suited for comparing to other similar facilities that do not have work zones in place, and can be a simple way of assessing the general effects of work zones on the corridor if data had not been collected prior to the deployment of the work zone(s). If data before the work zones were deployed is available, it is also possible to compute a change in a unit travel time measure.

A fairly broad list of delay-based performance measures are also defined in Table 3-6. Average delays per vehicle are fairly well understood by the driving public, as are indications of the likelihood of being delayed (expressed as a percentage of vehicles delayed). Some agencies may choose to quantify any delays that occur at a work zone; others may choose to quantify only those that exceed a threshold defined in their safety and mobility policy. Given that most work zones will not experience travel delays at all times of the day or night, emphasis may be given to evaluating peak periods only or periods when work zone capacity is reduced (such as during temporary lane closures or full roadway closures). From an overall process assessment perspective, the number (or percentage) of work zones that experience delays that exceed an agency's delay threshold can be a useful performance measure as well.

The majority of the measures listed pertain to vehicular travel (i.e., delay per vehicle, vehicles experiencing queues greater than some threshold), which are generally easier to collect or estimate than person travel. However, if a work zone is likely to alter modal splits on a facility due to demand management strategies encouraging carpooling or transit use, per-person measures may be more appropriate to use.

Table 3-5. Examples of Specific Throughput Performance Measures

Measure	Computations Required	Value or Importance Ranking	Potential Audience(s)
Reduction in maximum throughput during specific work tasks	Maximum throughput flow rate before – Maximum throughput flow rate during work task	High	MOT design practitioners, Work zone operations practitioners
Reduction in maximum throughput when work zone is inactive	Maximum throughput flow rate before – Maximum throughput flow rate during work inactivity period	High	MOT design practitioners, Work zone operations practitioners
Maximum vehicle throughput per hour or other period	Maximum throughput flow rate during work zone	High	MOT design practitioners, Work zone operations practitioners
Maximum person throughput (per hour or other period)	Maximum throughput flow rate during work zone period of interest · Average vehicle occupancy rate in the work zone	Moderate	MOT design practitioners, Work zone operations practitioners

Maximum throughput values described in this table should be based on a sustained volume (such as a continuous hour), and not on peak flow rates over short (i.e., 5- or 15-minute) time periods. If desired, maximum throughput data collected on different days can be averaged together as long as the same basic condition (number of lanes open, presence of work vehicles, etc.) are the same on each day.

Table 3-6. Examples of Specific Unit Travel Time and Delay Measures

Measure	Computations Required	Value or Importance Ranking	Potential Audience(s)
Average unit travel time for a given period or speed along a corridor with two or more work zones	Obtain an average total travel time through the corridor for the period of interest (peak period, during a particular phase or work activity, etc.) and divide by the length of the travel time route used.	High	All
Average unit travel time or speed through the work zone during a given period	Obtain an average total travel time through the work zone for the period of interest (peak period, during a particular phase or work activity, etc.) and divide by the length of the travel time route through the work zone.	High	All
Average per vehicle delays along a corridor in a given period due to work zones	Obtain an average total travel time through the corridor under non-work zone conditions for the period of interest.[a] Determine the average total travel time for the same roadway segment and period when work zones are present. Subtract the two to determine the per vehicle delay due to the work zones during the period of interest	High	Traveling public, Work zone operations practitioners
Delay per vehicle in a given time period through a work zone	Obtain an average travel time under non-work zone conditions for the period of interest and the roadway segment where the work zone will occur.[a] Determine the average total travel time for the same roadway segment and period when the work zone is present. Subtract the two to determine the per vehicle delay due to the work zone during the period of interest	High	All
Percent of time (for the period of interest) when delay per vehicle exceeds a threshold	Determine the total amount of time that a work zone is present for the periods of interest (e.g., the total hours that the work zone has a temporary lane closure in place). Determine the number of hours in those periods that the delay exceeded the threshold. Divide the "exceeds delay threshold" hours by the total hours of interest.	High	Work zone operations practitioners
Total vehicle-hours of delay per time period due to work zones located along a corridor	Determine average vehicle delays due to work zones along a corridor for the periods of interest. Determine total demand volumes in the corridor during the period. Multiply volume by the per vehicle delay.	Moderate	Work zone operations practitioners

Table 3-6. Examples of Specific Unit Travel Time and Delay Measures (Continued)

Measure	Computations Required	Value or Importance Ranking	Potential Audience(s)
Time required to convey delay information to drivers or pedestrians in corridor	Determine the average time it takes from the time a determination of the amount of delay present in the work zone is made to when it is posted on a sign, website, text message, etc.	Moderate	Work zone operations practitioners
Percent of projects along a corridor where delays exceed a threshold for a duration greater than a threshold	Determine each work zone in the corridor where delays exceeded the defined threshold at least once. Divide by the total number of work zones that occurred along that corridor.	Moderate	Work zone operations practitioners
Percent of travelers along a corridor that experience delay due to one or more work zones	Determine periods when work zones are creating delays along the corridor. Determine demand volumes during those periods, and for the entire day. Divide the volumes during periods of delay by the total daily volume.	Moderate	Work zone operations practitioners
Percent of travelers who experience a delay through a project	Determine the periods when the work zone creates delay. Determine demand volumes during those periods, and for the entire day. Divide the volumes during periods of delay by the total daily volume at the work zone.[b]	Moderate	Work zone operations practitioners

[a] For travel corridors that normally operate at near free-flow speeds during the time period, data collection before work zone implementation may not be needed. Rather, normal travel times may be estimated as the distance of the corridor divided by the normal speed of traffic.

[b] If the work zone does not create a day on each of the periods (because volumes in a given period may change depending on the day of the week), this measure may be defined as the percentage of volumes travel through the work zone in the period of interest that experience delay.

3.2.4 Specific Travel Time Reliability Measures

Travel time reliability on a facility may be adversely affected by the deployment of a work zone by increasing the adverse effects of weather, incidents, or even peak period recurrent congestion. When conditions prior to the initiation of the work zone are good, the computation of travel time reliability measures may be somewhat redundant with the other types of mobility measures that can be computed more simply. However, when the roadway segment is already experiencing a significant amount of travel time delays and traffic congestion prior to the start of the work zone, it may be important to track travel time reliability during the work zone to more fully capture the effects of work upon mobility. The measures shown in Table 3-7 identify three of the major indices currently used for travel time reliability measurement. Presently, all three of these measures are somewhat difficult to convey to the traveling public, and so are useful primarily to practitioners with day-to-day operational responsibility of the work zones.

Travel time reliability can be a useful work zone mobility performance measure on roadways already experiencing recurrent and non-recurrent congestion.

3.2.5 Specific Traffic Queue Measures

Table 3-8 presents a number of possible performance measures to characterize traffic queues that may develop in work zones. The measures reflect both project-level assessments (queue durations and lengths that occur at a given work zone) as well as broader region or jurisdictional assessments (percentage of projects experiencing queues that exceed time and/or length thresholds).

Traffic queues tend to be highly variable and dynamic in work zones, as they are very sensitive to changes in both demand volumes and the capacity of the work zone. Furthermore, once a queue develops, the capacity of the work zone often dips as traffic moves from a uniform travel speed condition to one of stop-and-go behavior approaching and passing through the work zone bottleneck. Capturing the percentage of time that a queue is present thus requires almost continuous monitoring and collection or documentation when such queues develop.

Table 3-7. Examples of Specific Travel Time Reliability Performance Measures

Measure	Computations Required	Value or Importance Ranking	Potential Audience(s)
Change in xx-percentile travel time through the limits of a project, or along a route where one or more work zones are located	Collect travel time data across multiple days for the time period of interest prior to work zone deployment. Order travel times from lowest to highest. Determine the xx-percentile highest travel time in the sample. Repeat once work zone is deployed. Compute the difference between the two times.	High	Work zone operations practitioners
Change in planning index through the limits of the work zone or along a route where one or more work zones are located	Collect travel time data across multiple days for the time period of interest prior to work zone deployment. Determine the average travel time during that period. Determine the free-flow travel time on that roadway segment and divide into the average travel time. Repeat once work zone is deployed. Compute the difference between the two indices.	Moderate	Work zone operations practitioners
Change in buffer index through the limits of the work zone or along a route where one or more work zones are located	Collect travel time data across multiple days for the time period of interest prior to work zone deployment. Determine the average travel time during that period, and the xx-percentile travel time (the 95^{th} percentile travel time is often used). Divide the xx-percentile travel time by the average travel time to obtain the buffer index. Repeat once the work zone is deployed. Compute the difference between these two indices.	Moderate low	Work zone operations practitioners

Table 3-8. Examples of Specific Traffic Queue Measures

Measure	Computations Required	Value or Importance Ranking	Potential Audience(s)
Average queue duration for a given time period, set of work activity periods, etc.	Obtain beginning and ending times of queues within the periods of interest over several days. Sum the amount of queuing time each day and divide by the number of days of data used. An agency may prefer to compute the average duration only for the periods when a queue actually occurred. In this case, the measure is the average queue duration when a queue is present in a given time period, set of work activity periods, etc.	High	All
Percent of time when queues occur in a given time period, set of work activity periods, etc.	Obtain beginning and ending times of queues within the periods of interest over several days. Sum the queue time for those periods across the days sampled. Divide by the sum of total time in those periods for those same days.	High	MOT design practitioners, Work zone operations practitioners
Percent of time when a queue exceeds a threshold in a given time period, set of work activity periods, etc.	Computed the same way as for the previous measure, with the caveat that queue times are not counted unless they exceed the threshold value.	High	MOT design practitioners, Work zone operations practitioners
Maximum queue length for a given time period, set of work activity periods, etc.	Obtain queue length data from the periods of interest over the duration of the work zone. Determine the maximum queue length recorded.	High	All
Maximum total length of queue along a corridor experienced by a traveler due to one or more work zones	Obtain queue length data from each work zone along a corridor for the periods of interest over a series of days. For each day of data, combine queue lengths observed at similar times to estimate the total combined length of queues at those time intervals. Determine the maximum total queue length recorded.	High	Traveling public, Work zone operations practitioners

Table 3-8. Examples of Specific Traffic Queue Measures (Continued)

Measure	Computations Required	Value or Importance Ranking	Potential Audience(s)
Average length of queue in a given time period, set of work activity periods, etc.	Obtain the beginning and ending times of queues, and queue length data at regular intervals over the period of interest on each of several days. For each sampling interval, compute an average queue length for that interval. Multiply those average queue lengths by duration of that interval, and divide by the total duration of queue measured in the period of interest across the days that were sampled.	High	Traveling public, Work zone operations practitioners
Percent of work zones with maximum queue length exceeding a threshold for a duration greater than a threshold	Obtain queue length data from each work zone being monitored. Identify times when queue lengths exceeded a defined length threshold for a period of time longer than a defined duration threshold. Divide the number of work zones exceeding these thresholds by the total number of work zones that were monitored.	Moderate	Work zone operations practitioners
Percent of travelers who experience a queue in a given time period, set of work activity periods, etc.	Obtain beginning and ending times of queues in the period of interest on several days. Determine demand volumes occurring on each of those days during the period of interest, and during the times when a queue was determined to be present. Divide the total period demand volumes by the demand volumes when queues were present. If desired, the entire daily demand volume may be used instead of the demand volumes just during the period of interest.	Moderate	MOT design practitioners, Work zone operations practitioners

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4.0 DATA SOURCES AND COMPUTATIONAL METHODS FOR SAFETY-RELATED PERFORMANCE MEASURES

The safety effects of work zones have long been a major concern of both transportation agencies and highway contractors. However, the monitoring and systematic improvement of work zone safety remains a challenge. Work zones are highly variable, the combined result of decisions regarding specific work zone design elements to use, traffic handling strategies to employ, scheduling choices, signing, special traffic management strategies, and other aspects. Work zones also involve periodic changes to the overall layout and design as work progresses through various phases of a project. In some cases, multiple traffic handling schemes are overlaid on one another, such as during temporary lane closures performed within a large construction project that has already implemented long-term lane and shoulder closures, lane shifts, etc.

Complicating matters further is the temporary nature of work zones themselves. Unlike traditional roadway design features that are implemented to last 30 to 50 years and for which significant amounts of data can be gathered over time to assess their safety implications, work zones can be in place for as little as a few minutes. Although some work zones are in place for several years, one typically has much less data to use to assess if and how safety is being impacted at that site.

Despite these challenges, work zone safety-related performance measures provide an opportunity for agencies to monitor performance in (near) real time, and to evaluate how decisions made regarding design and operations affected safety. Similar to mobility measures, work zones have several safety-related dimensions. Specifically, safety impacts are commonly described in terms of the following categories:

- Traffic crashes;
- Safety surrogates; and
- Worker accidents.

Although less numerous than for mobility measures, multiple data sources are available to assess these safety impacts. In some cases, data that already exists within an agency or is gathered as part of other agency requirements can be used; in other cases, data must be collected in and around the work zone to measure safety impacts. A discussion of these various sources is presented in the following sections.

4.1 Safety-Related Data Sources

4.1.1 Crash Data Sources

Agencies and contractors alike are concerned about the frequency and severity of traffic crashes that occur in a work zone. Crashes in work zones often become sources of litigation, which can take several years and hundreds of thousands of dollars to resolve. More importantly, crashes are the most direct indicator of work zone traffic safety.

Many agencies monitor the number of fatalities that occur in work zones each year. Due to the small (fortunately) sample size of such crashes each year, it is difficult to gain much insight into the problems and/or possible countermeasures related to these crashes. Consequently, it is preferable to expand the analyses to injury (and, possibly, even property-damage-only [PDO]) crashes occurring in work zones. Furthermore, collation of crash data with specific work zone locations and times allows exposure and indicator/stratification data to be used to focus the monitoring and assessment efforts on specific phases, work zone design features, and/or work activities if so desired.

4.1.1.1 Sources That Already Exist

Traffic Crash Data That May be Available from Existing Agency Sources

- Statewide traffic crash records database entries
- Electronic or hard copies of crash report forms obtained directly from investing law enforcement officers
- TOC incident database entries
- Dispatch Logs (or Electronic Database) of Emergency Response or Service Patrols

Data from existing agency sources – Each state has a statewide crash records database that is used to systematically evaluate crash patterns and prioritize safety improvements to be made as part of each state's highway safety improvement program. These data come from the crash report form that is prepared by the investigating officer of a crash. The report and database contains a wide range of details regarding the roadway location, the vehicles, and the drivers/passengers/pedestrians involved. Most states also have a field on the form that officers can code if the crash occurred in a work zone. Some of these states have additional fields to document the type of work zone (lane closure, lane shift, shoulder work, or moving work operation), the location of the crash in the work zone, and whether workers or law enforcement personnel were present. The accuracy of the data entered into these fields is believed to vary considerably from jurisdiction to jurisdiction, as a basic understanding of work zone traffic control concepts is required to properly code the fields.

There is typically a lag between when the crash occurs and a report is filled out, and the time that it shows up in the database. In some jurisdictions, the lag may be only a few weeks; in others, it may be several months. Especially long lag times hinder the ability of practitioners to monitor the ongoing safety record of a work zone while it is in place. In fact, the lag time may be so long that the project itself is completed before any crash data occurring during the project is made available.

To mitigate the large lag times some agencies experience in obtaining crash information through their statewide database, some practitioners choose to manually collect copies of the actual crash reports occurring at a select number of work zones directly from the law enforcement agencies with jurisdiction over each work zone of interest. Transportation agency staff typically meets with the local enforcement agency to describe the need for the data and set up a recurrent collection schedule of copies of the report form itself. The copy may be physical or electronic photocopies, depending on the available technology in the enforcement agency office. Practitioners who obtain these report copies must enter them physically into a spreadsheet or other database in order to perform the desired analyses. As part of that process, the practitioner may have to make judgments for certain database elements. Some agencies, for example, determine a manner of collision code after reviewing the crash report form and narrative itself rather than have the investigating officer make that decision. The practitioner may also need to contact more than one enforcement agency office if the work zone crosses jurisdictional boundaries or if crashes on the roadway can be investigated by several possible enforcement agencies (state highway patrol, sheriff, local police department, etc.).

The Ohio Department of Transportation personnel gather hard copies of police crash reports at major projects every two weeks and manually code that data into a database so that current crash statistics on those projects can be monitored (*1*).

A third option that may exist for those work zones located within the limits of a TOC is to use incident logs recorded by system operators. Most centers document the incidents that occur within system boundaries, and can be readily extracted from the database by identifying the location and time periods of interest. An example of a safety dashboard that FAST personnel in Las Vegas have developed that can be used to evaluate work zone crash trends on a project is shown in Figure 4-1. Many of the recorded incidents may be minor PDO crashes that will not meet the agency's reporting threshold for its statewide crash database. Consequently, it will be necessary to compare any incident data during a work zone to similar incident data collected at the same location and for a similar period of time prior to the initiation of the work zone. It should also be noted that most incident databases will include non-crash events (stalled vehicles, debris in road, etc.) that will need to be extracted prior to analysis.

Similar to the use of a TOC incident database, some agencies may be able to access and use the dispatch logs or database of emergency response or service patrol personnel to a work zone. One would expect fairly good correlation between emergency response dispatches and crash reports that eventually end up in the statewide database. However, it will be necessary to pull out the non-traffic crash events that are likely to exist in both types of logs or databases. It is likely that some privacy concerns would need to be addressed as well before such data could be pulled and used for performance measurement purposes.

The New Hampshire Department of Transportation examines freeway service patrol and fire dispatch calls throughout key work zones, with exceptionally high dispatch volume to a specific location serving as an indication of a potential safety problem in the work zone (*1*).

Brian Hoeft, Freeway and Arterial System for Transportation (FAST), Regional Transportation Commission of Southern Nevada, Las Vegas, Nevada

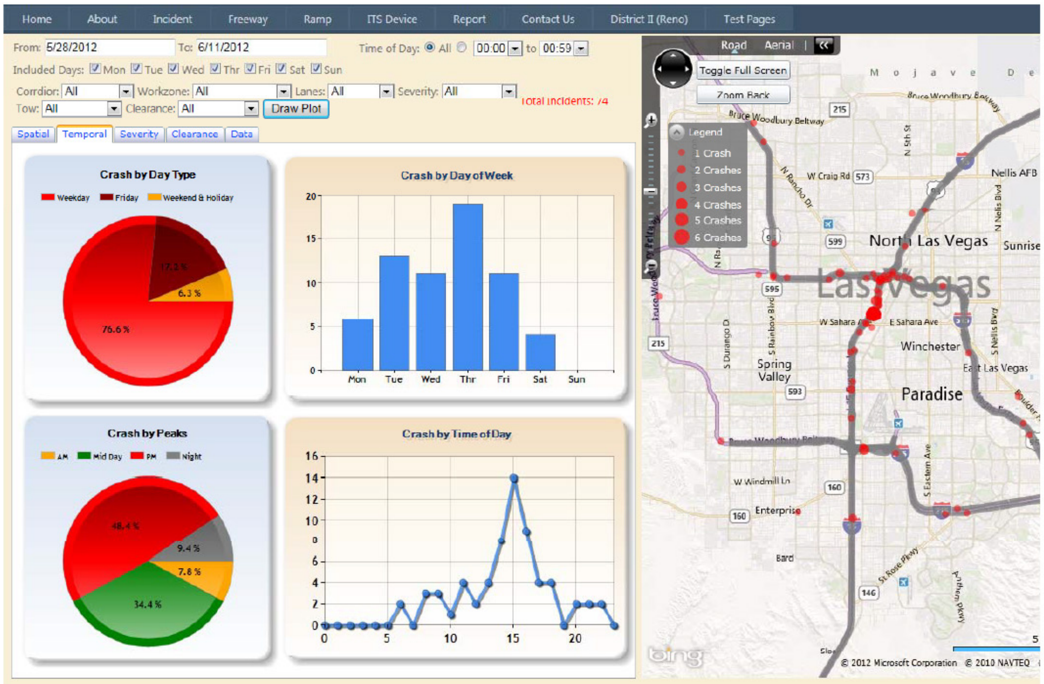

Figure 4-1. Crash Dashboard In Use by FAST Personnel in Las Vegas, NV

4.1.1.2 Potential Sources in the Near Future

> **Traffic Crash Data Potentially Available in the Future**
>
> - Work zone crash data collected directly by agency staff
> - Connected vehicle initiative data

Work zone crash and accident data collected by agency staff – As noted above, data collected as part of regular traffic crash investigations law enforcement officers typically has very limited information regarding specific features of the work zone itself. Project information, type of work being performed, type of traffic control devices in use, whether or not vehicles intruded into the work space, etc., will generally not be captured in a statewide database, and may or may not be documented in the narrative or diagram of a crash report form. Consequently, a few agencies rely on their own staff to collect specific work zone data present when a traffic crash occurs. New York State DOT staff does this for each work zone crash occurrence during active work hours, and for those it is notified about when the work zone is inactive. Agency staff then enters this information into an internal database for analysis (a few other states perform a less rigorous data collection effort, often limiting it to fatalities or very severe crashes). Analysis of these data can assist the agency in identifying traffic control set up errors

> *Establishing and using an agency-collected work zone crash database requires the support of senior management.*

or other issues that should be corrected. The process captures most, but not all traffic crashes. As a result, it is not possible to perform accurate before-during comparisons of these data to the statewide crash records database. Likewise, it is not feasible to combine these data with exposure or work zone indicator/stratification data to develop rate-based measures. However, the data can be useful in assessing the relative frequency of different work zone elements and element combinations involved in work zone crashes. A significant effort is required to establish protocols and documentation procedures to make this happen. Therefore, it requires the support and emphasis of an agency's senior management in order to be successful.

Connected vehicle initiative – As with most of the mobility-related work zone performance measure data sources, the connected vehicle initiative does offer potential as a future work zone crash performance measure data source as well. Work zones equipped with electronic infrastructure that can receive vehicle data about collisions in real time could offer agencies the opportunity to continuously monitor and update crash information at a work zone. Combined with other types of location-based electronic information about the roadway and the work zone itself, an agency could establish a variety of near-real-time dashboard metrics regarding work zone crashes overall and by type of roadway, work operations, etc.

4.1.1.3 Key Considerations and Trade-offs of Work Zone Traffic Crash Data Sources

Table 4-1 provides a summary of the key considerations and trade-offs regarding the use of each of the work zone crash data sources described above. The appropriate data source will depend on the intended use. For monitoring of current work zones, the ability to obtain the data as quickly after a crash occurs as possible is critical. For comparisons across work zones or work zone operations, or for assessments of the relative effects of design or strategy decisions upon safety which require a more rigorous analysis and comparison to baseline or "expected" conditions, a complete and stable data source over multiple years is important.

Table 4-1. Considerations and Trade-offs of Traffic Crash Data Sources

Data Source	Key Considerations and Trade-offs
Statewide Crash Records Database	• Information regarding work zone features and activities is limited • Significant time lags can exist in obtaining crash data for a given work zone
Electronic or hard copies of crash report forms from investigating law enforcement officers	• Information regarding work zone features and activities is limited • Requires agency staff to obtain and then manually code the reports into a spreadsheet or database for analysis • May require interaction with multiple law enforcement agencies to obtain all reports
TOC operator incident logs	• Will include non-reported as well as reported crashes • Will include non-crash events
Dispatch Logs (or Electronic Database) of Emergency Response or Service Patrols	• Likely to include non-traffic crash events as well • Potential privacy concerns
Agency-collected crash and work zone database	• Significant agency effort will be required during initial phases, and for ongoing maintenance of the process • Requires upper agency support and emphasis
Connected vehicle data	• Date of availability still uncertain

4.1.2 Safety Surrogate Data Sources

One of the challenges in using actual crash data for performance monitoring and measurement is that crashes are rare events, and obtaining a large enough sample to draw reasonable conclusions about the safety of a work zone can take a considerable amount of time. Therefore, it can be beneficial to look at certain operational performance data that are believed to be correlated to traffic safety at the work zone. Traffic speeds, changes in speed, and speed variance are commonly-used safety surrogate measures. Erratic maneuvers and vehicle conflicts are other examples. The sections below identify the major sources of work zone safety surrogate data.

4.1.2.1 Sources That Already Exist

> **Safety Surrogate Data That May be Collected Specifically for the Work Zone**
>
> - Speed data collected by hand-held devices (radar, lidar)
> - Speed data extracted from work zone ITS sensors
> - Travel times through the work zone
> - Videotaped traffic behaviors at key locations
> - Work zone inspection scores

Data collected specifically for a work zone – Work zones located within the surveillance limits of a TOC may have spot speed sensor data available that could be employed for safety surrogate purposes, if the sensor is located where speed data would be beneficial. As described in the previous chapter on mobility-related data sources, it is important to verify the availability of TOC sensor data during the work zone prior to the project being initiated.

Meanwhile, a number of data sources obtained specifically from a work zone can be used for safety surrogate purposes. Data collection personnel can use hand-held radar or lidar devices to easily obtain a sample of speeds at one or more locations before and within a work zone. Standard procedures for collecting this type of data exist in many traffic engineering manuals. Any spot speed sensors that are part of a work zone ITS deployment could also be used. Travel time data, collected as described in the previous chapter, can also be used to assess the speed being driven through a work zone relative to the posted speed limit.

Moving away from speed-related data as a surrogate of safety, the positioning of cameras at key trouble spots to videotape driving behaviors can be an effective source of safety surrogate data. Rates of erratic maneuvers and vehicle conflicts occurring at the location can be extracted manually from the video, and yield insights into the magnitude of possible safety problems at a location. The data can also indicate whether the implementation of a countermeasure to reduce such behavior has been successful. This approach relies heavily upon the skill of the analyst in defining specific movements and behaviors that constitute erratic or conflicting behavior, such as the severe braking maneuvers, last-minute lane changes, near miss sideswipes, etc.

Finally, most agencies and contractors perform regular inspections of the temporary traffic control devices in place in a work zone. A few, however, formalize the inspection process by establishing specific levels of acceptability/effectiveness of devices and the overall time-to-collision (TTC) system and performing a detailed scored inspection of the work zone. These scores are then tallied to identify areas of needed improvement for the work zone. The scores can also be compared across work zones to identify patterns of deficiencies, establish baseline standards, and evaluate improvement efforts. An example of a form utilized by the Oregon Department of Transportation is illustrated in Figure 4-2.

Traffic Control Plans Unit. *2009 Construction Work Zone Tour.* Oregon Department of Transportation, Salem, OR

2012 WORK ZONE SAFETY AUDITS - EVALUATION FORM

PROJECT NAME: DATE:

HIGHWAY: MILEPOST: REGION: REVIEWED BY:

PROJECT MANAGER: OTHER CONTACTS:

CONTRACTOR: TCS

GENERAL NOTES

Only score Devices you witnessed on the Project. If a certain device was not present, do not score it.

S C O R I N G

Notify PM or Field Project Representive!				BELOW AVG.	AVERAGE	ABOVE AVG.	GOOD	VERY GOOD	EXCELLENT
1	2	3	4	5	6	7	8	9	10

CATEGORIES		SCORE	NOTES
TEMPORARY SIGNING (Signs, Flags, Supports)	QUALITY		
	PLACEMENT		
	SPACING		
CHANNELIZATION DEVICES (Tubular Markers, Cones, Drums, Barricades)	Tubes/Cones		
	DRUMS		
	BARRICADES		
PAVEMENT MARKINGS (Paint, Tape, Reflective & Flexible Markers)	CONDITION		
	PLACEMENT		
CONCRETE BARRIER	CONDITION		
	PLACEMENT		
Reflective Barrier Panels? Y or N	CONDITION		
IMPACT ATTENUATORS (Drum Arrays, Narrow-Site & TMA)	CONDITION		
	PLACEMENT		
PORTABLE CHANGEABLE MESSAGE SIGNS (PCMS)	MESSAGE		Capture message, if possible
	PLACEMENT		
	CONDITION		
SEQUENTIAL ARROW PANEL (Arrow Board)	PLACEMENT		
	CONDITION		
TEMP. TRAFFIC SIGNALS	SET-UP		
	CONDITION		
BICYCLE, PEDESTRIAN & ADA FACILITIES (Score if existing facilities affected by construction)	SIGNING		
	Continuous Route?		
	ADA Compliance		
FLAGGERS	VISIBILITY		
	Performance		
PILOT CARS	Equipment		
	Performance		
MOBILITY	Overall Flow		
Time Stopped At Flagger or Signal (if applicable)		min	
Approx. Travel Speed thru the work zone?		mph	
WORKER GARMENTS & EQUIPMENT	GARMENTS		
	EQUIPMENT		
SITE HOUSEKEEPING	CLEAN, ORDERLY		
POLICE ENFORCEMENT	ON-SITE?	Y or N	
	PAYING OT?	Y or N	
DRIVER-FRIENDLY WORK ZONE	Ease of Navigation		This category for information only. Do not include in Page Total.
	Consistency		

GRAND TOTAL = [ ] ÷ [N*] = *FINAL SCORE* [ ]

* N = The Number of Scored Categories

EvaluationForm.xls Project #1

Figure 4-2. Example of the Inspection Form Used by Oregon DOT

4.1.2.2 Potential Sources in the Near Future

Microscopic traffic simulation – Traffic simulation is a powerful alternatives analysis tool used for a variety of operational assessments. Simulation has been used to compare and rank various work zone traffic control strategies such as speed and merge control, queue warning systems, ramp metering on freeways and signal timing changes on connected arterials, or any combinations of these.

Although traditionally used to assess the operational efficiency and mobility impacts of various alternatives, some users dig deeper into the simulation output to extract data that can, in theory, be used as safety surrogates. The FHWA has sponsored research into the development and testing of such a safety surrogate assessment model (SSAM) (*11, 12*). The tool takes the output from one of the traffic simulation models and processes the output to yield the following potential safety surrogate measures:

- Minimum TTC
- Minimum post-encroachment time
- Initial deceleration rate
- Maximum deceleration rate
- Maximum speed
- Maximum speed differential
- Classification as lane-change, rear-end, or path-crossing event type
- Vehicle velocity change had the event proceeded to a crash

Gettman, D., L. Pu, T. Sayed, and S. Shelby. Surrogate Safety Assessment Model and Validation: Final Report. Report No. FHWA-HRT-08-051. FHWA, U.S. Department of Transportation, Washington, DC. May 2008. Accessible at http://www.fhwa.dot.gov/publications/research/safety/08051/08051.pdf

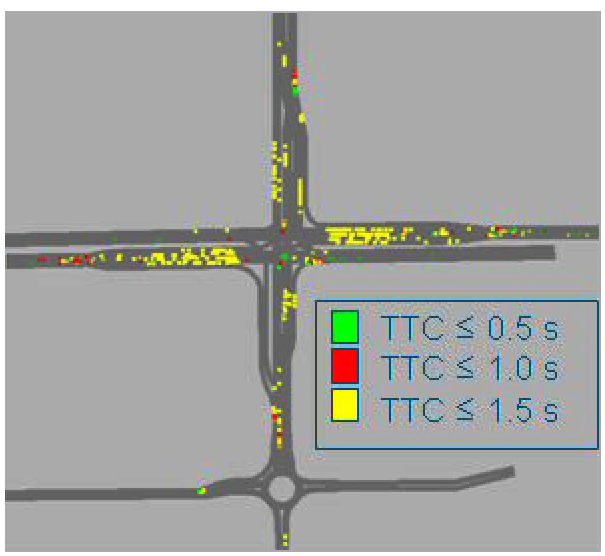

Figure 4-3. TTC is one Type of Safety Surrogate Data that can be Extracted from Traffic Simulation Model Output

Some safety surrogates (e.g. speed variance) can be relatively easily obtained using virtual detectors. Others, such as decelerations and TTC estimates, require some significant post-processing of the simulation output (which is why the SSAM was developed). However, coding and calibrating a simulation model to use with SSAM does take considerable time and effort to do correctly. At the same time, it is not yet clear whether the underlying traffic behavior algorithms in the models accurately represent how the introduction of a work zone onto a roadway truly affects the safety surrogate outputs.

The **connected vehicle initiative** already mentioned multiple times in this document is also expected to be a useful source of safety surrogate data at work zones in the future. The same types of measures listed above that are computed through traffic simulation (encroachments, deceleration rates, speed differentials between vehicles, etc.) will likely be available from actual vehicles through this initiative. Extraction and analysis of this data should yield valuable insights into work zone features and conditions that contribute to higher crash frequencies, and conversely to those features that promote safer vehicle operations.

4.1.2.3 Key Considerations and Trade-offs of Safety Surrogate Data Sources

Table 4-2 summarizes the key considerations and trade-offs associated with the various types of safety surrogate data that could be used for work zone performance measurement. One of the key considerations of all of the possible data sources described is the fact that the assumptions that such data is indeed correlated to work zone safety and crash experiences has not yet been verified. However, since essentially all of the data sources can be obtained from a work zone fairly quickly, they can help identify potential safety concerns and problem locations much faster than can be accomplished using actual crash data alone. As such, agencies and contractors should consider the collection and use of safety surrogate data as a good compliment to work zone crash monitoring and analyses.

Table 4-2. Considerations and Trade-offs of Traffic Safety Surrogate Data Sources

Data Source	Key Considerations and Trade-offs
All data types	• Correlation of surrogate data to work zone crashes and safety have not yet been fully verified • Most surrogate data can be obtained relatively quickly
TOC or work zone ITS speed sensor data	• Value of data depends on the locations of the sensors. • Important to verify that data will be available once work has started (no loss of power to sensors), and will be archived and available for analysis
Speed data collected with hand-held radar or lidar	• Data collection is fairly easy to accomplish, as long as a suitable location for data collection can be found • Useful for assessing speed behaviors at locations upstream or within the work zone of specific interest concern • Care should be taken to be as inconspicuous as possible so as to not bias the behavior of approaching drivers
Travel times through the work zone to assess speed limit compliance	• Locations where significant speed changes are required can indicate potential problem locations • Can be an easy way to assess the overall level of compliance with the work zone speed limit
Videotaped traffic behavior analyzed to determine erratic maneuver and vehicle conflict rates	• Can be difficult to find a unobtrusive vantage point from which to view and record traffic • Analysis of data is very labor intensive • Definition of specific behaviors of interest is needed to minimize biases of individuals performing data reduction
Work zone inspection scores	• Requires significant effort up front to establish scoring and rating system to be used by inspectors • Correlation of scores to actual safety levels in work zone have not been verified
Traffic simulation output (analyzed with SSAM)	• Significant effort and technical skill are required to code and calibrate a traffic simulation model • Correlation of safety surrogate measures to actual conditions that develop in a work zone have not been fully verified • Correlation of safety surrogate results to work zone safety have also not been verified
Connected vehicle data	• Date of availability still uncertain

4.1.3 Worker Accident Data Sources

The previous sections on crashes and safety surrogate data emphasize the traffic safety aspect of work zone performance. Although traffic safety is indeed of paramount importance to both agencies and contractors, the safety of their own employees is equally important. Accident statistics indicate that more highway workers are injured by work equipment and work vehicles within the work space than by traffic passing by or intruding into the work zone.

4.1.3.1 Sources That Already Exist

Worker Accident Data Collected Specifically for the Work Zone

- Agency or contractor worker injury records
- State worker compensation commission accident statistics
- Bureau of Labor Statistics database

Data collected specifically for a work zone – The Occupational Safety and Health Administration (OSHA) requires all employers with 11 or more employees to keep injury and illness records of its employees and to post them each year. Injuries and fatalities are then reported to OSHA, who may request the accident records as well. OSHA and the Bureau of Labor Statistics (BLS) track accident statistics across the country for the various job classifications, including the construction industry. Therefore, agency or contractor injury records themselves are the main sources of worker accident data available. OSHA provides some guidance on the key elements to include in an accident report.

The Bureau of Labor Statistics, United States Department of Labor tracks health statistics for occupations, including highway construction (*13*).

Certainly, each agency or contractor will have ready access to its own worker accident data. For a smaller contractor, the amount of worker accident data available will be fairly small; for large agencies and contractors, the amount of worker injury data collected will be greater. However, interest may exist in how those data compare to other contractors in general, to other agencies, etc. Fortunately, state workers compensation commissions can provide basic accident trends at a fairly aggregate level (such as for highway construction employers). Likewise, accident statistics available through the BLS can shed light on basic trends regarding injuries occurring in the highway and heavy construction field nationally. Although causal or contributory factors will not generally exist in these databases, relative frequencies of types of injuries, overall accident rates, etc. may be accessible for comparison purposes. OSHA also publishes some statistics on overall worker accidents (and accident rates as a function of hours worked) for comparison as well.

4.1.3.2 Possible Sources in the Near Future

The New York State DOT construction accident record keeping program requires contractors to provide accident data on worker injuries occurring during highway work activities. Information on types of injuries, and narratives as to the events leading up to the accidents, have been useful in post-accident reviews of trends by the agency. In turn, the agency has enacted increased training, awareness programs, etc. to try and reduce some of the more common accidents. Other agencies may eventually choose to adopt a similar data collection and assessment approach. Of course, the same issues that existed for the collection of traffic crash data, such as the upfront costs and efforts to establish a program and the allocation of resources to maintain it over time, will exist here as well.

4.1.3.3 Key Considerations and Trade-offs of Worker Accident Data Sources

A summary of the key considerations and trade-offs associated with the various sources of worker accident data are presented in Table 4-3.

Table 4-3. Considerations and Trade-offs of Worker Accident Data Sources

Data Source	Key Considerations and Trade-offs
Agency or contractor worker injury records	• Use of accident reports must be monitored carefully due to privacy concerns for the individual having the accident • Sample size for many smaller companies will be fairly small, making it difficult to clearly identify any trends that can be mitigated
State worker compensation commission statistics	• Useful for comparisons to agency or contractor accident trends • Level of detail will be limited
Bureau of Labor Statistics, OSHA worker accident statistics	• Useful for comparisons to agency or contractor accident trends • Level of detail will be limited
Worker accident information in an agency-collected work zone crash and accident database	• Significant agency effort will be required during initial start up, and for ongoing maintenance of the process • Requires upper agency support and emphasis • Use of accident reports must be monitored carefully due to privacy concerns for the individual having the accident

4.2 Identifying and Computing Specific Safety Measures of Interest

4.2.1 General Considerations

Work zone safety performance measures can be useful to agencies and contractors in at least two ways:

1. To determine whether a safety problem exists at a particular work zone, so that an assessment can be initiated to determine if the issue or issues can be corrected while the work zone is still in place;
2. To determine how a specific work zone design feature or combination of features, operating strategy, etc. affects the safety performance of a work zone, so that future decisions about the work zone design or maintenance of traffic plan are improved.

In both cases, one of the key challenges is in developing a reasonable level of confidence in the conclusions reached about the data. Hopefully, both crash and worker accident data at any given project are relatively rare events. However, their rarity does make it difficult to determine whether the number or rate of crashes or accidents that occur over time is greater than what should be expected, or is within the range expected given the normal randomness of these events.

4.2.2 Specific Crash Measures

Table 4-4 illustrates four types of work zone traffic crash performance measures that were deemed to be of high or moderate importance by a panel of work zone practitioners. Although basic counts of crashes occurring at a project or over a region (many states track the total number of fatalities or fatal crashes that occur in their work zones each year) is commonly used as a performance measure, the real value in monitoring traffic crash counts is in assessing whether the number is greater than would be expected if the work zone were not present (and if so, by how much). Comparing the counts during the work zone period of interest to an average representing the same period prior to the work zone deployment is one way to assess if crashes have increased. Typically, a three-year average immediately prior to work zone deployment is used. However, this approach ignores the effect of any changes in traffic demand over time. In addition, this approach does not account for the stochastic nature of crashes themselves when comparing actual crash frequencies to what have been expected to occur if the work zone were not present.

A relatively simple procedure is available to assist in determining whether crashes have increased relative to what they would have been without the work zone (*14*). The following data are needed:

- the number of accidents observed during the work zone period of interest on the work zone segment of interest (L);
- the total number of accidents on the same segment and for the same period of interest in previous (pre-work zone) calendar years (K);
- the ratio of the work zone analysis period to the designated before period (r_d);
- an estimate of the ratio of traffic in the work zone to traffic on the same segment and during the same calendar period for three years prior ($\hat{r}_{tf}$); and
- the maximum percent safety reduction the district expects or is willing to accept ($\theta\%_{tolerable}$).

Table 4-4. Examples of Specific Work Zone Traffic Crash Performance Measures

Measure	Computations Required	Value or Importance Ranking	Potential Audience(s)
Number of crashes per time period of interest, change in crash frequency from the no-work zone condition	Use of simple crash counts does not require computations. Determination of how much the counts differ from what would have been "expected" had the work zone not been present is described in the text.	High	Traveling public Work zone operations practitioners
Change in crash rate per vehicle-mile-traveled per time period	Determine the number of crashes occurring during the period of interest (total project, certain phase, during peak periods, during certain work times). Compute the number of vehicles traveling through the work zone during the period and multiply by the length of the work zone to determine the VMT. Divide the number of crashes by the VMT. Compute for the same period of interest before the work zone was deployed. Determine the difference or percent change in rates.	High	Traveling public Work zone operations practitioners
Distribution of crashes (or changes in the distributions) by severity, type of crash, contributing factor, etc.	Determine which crash factors are of interest. Determine levels for each factor, and number of crashes in each level. Divide each level by the total number of crashes across all levels. Compute the same for data obtained before the work zone was deployed. Compare the distributions.	Moderate	Work zone design practitioners Work zone operations practitioners
Change in crash costs per time period of interest	Determine the number of crashes by severity over the work zone period of interest. Determine the expected number of crashes that would have occurred without the work zone present (described in the text). Determine the difference in crashes by severity. Multiply the difference in each severity level by the FHWA estimate of crash costs for that severity level. Sum across all severity levels.	Moderate	Work zone design practitioners

Many agencies or contractors are interested in whether crashes have increased at all during the work zone period. However, if an agency chooses to acknowledge that crashes do tend to increase somewhat when a work zone is present, and only wishes to determine if crashes at a given work zone increase by more than what is typical, they would make use of the $\theta\%_{tolerable}$ in the computations below.

Four computational steps are required:

Step 1. Estimate the safety of the work zone segment during the period of interest ($\hat{\lambda}$) and the variance of that estimate:

$$\hat{\lambda} = L$$

$$V\hat{A}R\{\hat{\lambda}\} = L$$

Step 2. Estimate what would have been the safety of the segment during the same time period had the work zone not been there ($\hat{\pi}$) and that variance of the estimate:

$$Expected\ crash\ frequency\ (\hat{\pi}) = r_d \hat{r}_{tf} K$$

$$V\hat{A}R\{\hat{\pi}\} = r_d^2 r_{tf}{}^2 K$$

The value for $\hat{\pi}$ is estimated using an "average" of the accident frequency on the same segment and during the same calendar period while accounting for changes in traffic volumes. A three-year average is recommended, reflecting a balance between the use of recent data and obtaining large enough sample sizes. If traffic has grown and is greater in the work zone than on the same segment for the three years prior, $\hat{r}_{tf}$ will be greater than 1. If traffic has decreased as a result of general trends or implementation of travel demand management strategies introduced as part of the temporary traffic management plan, then $\hat{r}_{tf}$ will be less than 1. If no information on traffic volumes is available, a value of 1.0 should be used for $\hat{r}_{tf}$.

Step 3. Estimate the tolerable work zone safety given the maximum safety reduction the district expects or is willing to accept ($\hat{\lambda}_{tolerable}$ ***) and the variance of that estimate:***

$$\hat{\lambda}_{tolerable} = \left(\frac{\theta\%_{tolerable}}{100\%} + 1 \right) * \hat{\pi}$$

$$V\hat{A}R\left\{\hat{\lambda}_{tolerable}\right\} = \left(\frac{\theta\%_{tolerable}}{100\%} + 1 \right)^2 * V\hat{A}R\{\hat{\pi}\}$$

Step 4. Determine if the safety of the work zone segment during the period of interest ($\hat{\lambda}$ ***) is worse than the expected or tolerable work zone safety (*** $\hat{\lambda}_{tolerable}$ ***) at the desired level of confidence (ε):***

$$\hat{\lambda} > \hat{\lambda}_{tolerable} + N(\varepsilon,0,1)\sqrt{V\hat{A}R\{\hat{\lambda}\} + V\hat{A}R\{\hat{\lambda}_{tolerable}\}}$$

Safety of the work zone segment during the period of interest is worse than expected or tolerable.

$$\hat{\lambda} \le \hat{\lambda}_{tolerable} + N(\varepsilon,0,1)\sqrt{V\hat{A}R\{\hat{\lambda}\} + V\hat{A}R\{\hat{\lambda}_{tolerable}\}}$$

There is not enough evidence to conclude that safety of the work zone segment during the period of interest is worse than expected or tolerable (with caveat explained below).

The $N(\varepsilon,0,1)$ value corresponds to the standard normal statistic for the confidence level of interest. If the agency or contractor wants to be 90 percent confident that the number of crashes exceeds the threshold expected value, the $N(\varepsilon,0,1)$ value would be 1.282. If the agency or contractor were only interested in a 50/50 guess as to whether the crash number exceeds the threshold, the $N(\varepsilon,0,1)$ value would be 0. A simple way to apply step 4 is presented in Figure 4-4. The x-axis represents the computed expected number of crashes of the segment during the time period of interest if the work zone was not there ($\hat{\pi}$). Values on the y-axis indicate the minimum number of work zone crashes observed during the period of interest that would indicate an increase in crashes had indeed occurred. Three levels of confidence are shown, 90 percent, 75 percent, and 50 percent. Note that the 50 percent "guess" is the same as the expected value without the work zone (as would be expected). Also note that crashes typically need to be 20 to 50 percent higher than expected to be 90 percent confident that crash frequency has indeed increased within the work zone.

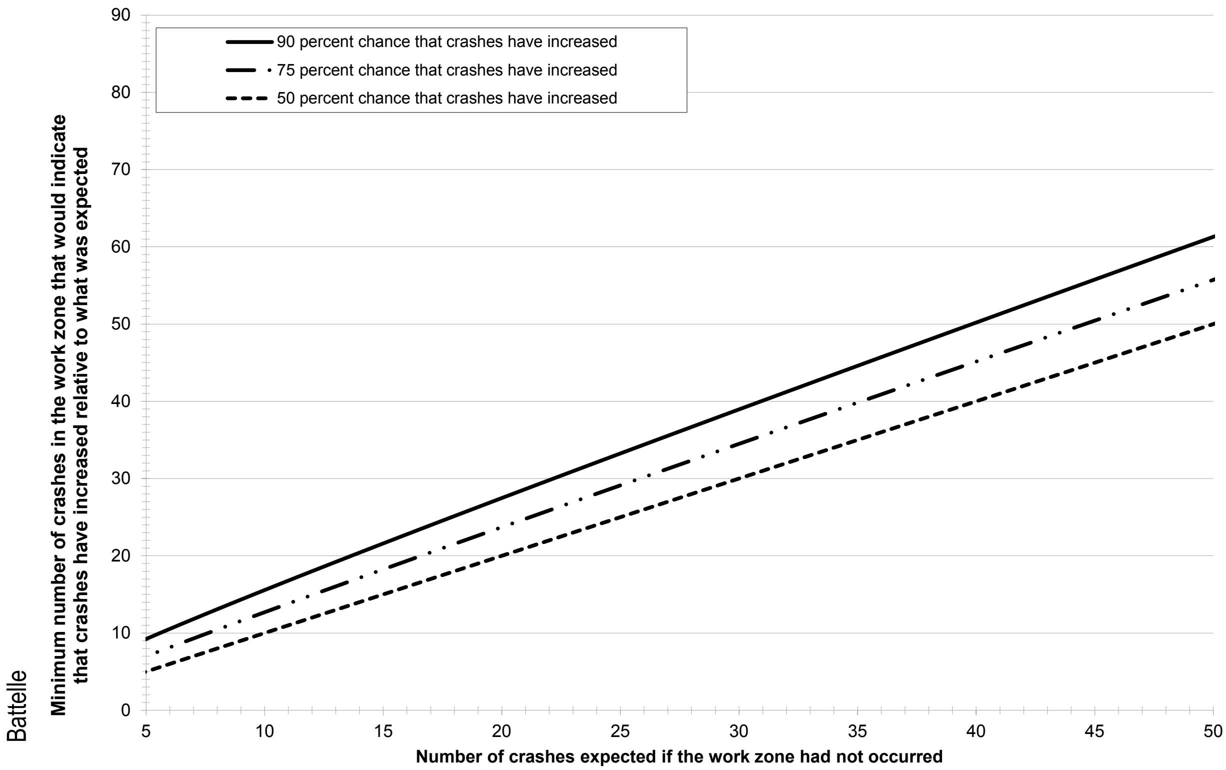

Figure 4-4. Determination of Whether Crashes have Increased Significantly in a Work Zone

Although the use of expected crash frequencies is the preferred approach for analyses, and is the approach followed in the recently-released *Highway Safety Manual* (*15*), some practitioners are more comfortable with using crash rates as a function of VMT. Despite the statistical limitations of this approach when the number of crashes being compared is fairly low, it can also be used to compare pre-work zone crash conditions with those occurring during the work zone.

4.2.3 Specific Safety Surrogate Measures

Table 4-5 provides a summary of work zone safety surrogate performance measures, how they were ranked by the practitioners, and their intended audience(s). Measures related to speeds are appealing to practitioners and understood by the traveling public, but have not been strongly correlated to safety. Several potential surrogate measures can be obtained through traffic simulation, but currently such measures are not highly rated by practitioners. Additional research and use of such measures will likely be needed before they are more readily adopted for work zone performance measurement.

Table 4-5. Examples of Specific Work Zone Safety Surrogate Crash Performance Measures

Measure	Computations Required	Value or Importance Ranking	Potential Audience(s)
Speed limit compliance percentage	General indication of compliance can be obtained through work zone drive throughs. Formal computations can be done with a sample of at least 120 spot speed samples at a location	High	Traveling public Work zone operations practitioners
Speed variance	Standard computation of the variance of a sample of speeds	High	Work zone operations practitioners
Change in emergency response or service patrol dispatches within a work zone	Computations should be performed similarly to those outlined for crash analyses.	Moderate	Work zone operations practitioners
Frequency of low time to collision rates	Frequency or rate during the work zone can be obtained through video analysis of erratic maneuver and vehicle conflict data. More often estimated as part of traffic simulation analyses.	Moderately Low	Work zone design practitioners
Work zone inspection scores	Inspection criteria can be scored numerically in various ways. Weightings and sums across various criteria is straightforward	Moderately Low	Work zone operations practitioners
Frequency of high deceleration rates	Frequency or rate during the work zone can be obtained through video analysis of erratic maneuver and vehicle conflict data. More often estimated as part of traffic simulation analyses.	Moderately Low	Work zone design practitioners
Frequency of forced merges per lane closure hour or number of vehicles	Frequency or rate during the work zone can be obtained through video analysis of erratic maneuver and vehicle conflict data. More often estimated as part of traffic simulation analyses.	Moderately Low	Work zone design practitioners
Frequency of very small headways	Frequency or rate during the work zone can be obtained through video analysis of erratic maneuver and vehicle conflict data. More often estimated as part of traffic simulation analyses.	Moderately Low	Work zone design practitioners

4.2.4 Specific Worker Accident Measures

Finally, Table 4-6 presents some work zone performance measures pertaining to worker accidents. Simple counts can be easily tracked by an agency or contractor, and are simple to interpret. If the target or expectation is low (i.e., zero occurrences for an agency or contractor in a given time period), the use of counts is meaningful. However, as the size of the agency or contractor increases, the frequencies of accidents would not be expected to be zero, and efforts to assess whether improvements are being made would necessitate rate-based metrics, commonly in terms of worker hours of exposure. For agencies and contractors with a substantial amount of worker accident data available, it can also be meaningful to look at accident trends in terms of types of injuries, contributing factors, etc. as percentages of the total dataset, and compare to statewide or national trends.

Table 4-6. Examples of Specific Worker Accident Performance Measures

Measure	Computations Required	Value or Importance Ranking	Potential Audience(s)
Frequency of worker accidents	No computations needed	High	Traveling public Work zone operations practitioners
Worker injury rates per person-hours of work (i.e., 200,000)	Determine frequency of worker accidents recorded in a given period divided by the total number of agency or contractor worker hours. These can be developed for a single work zone (if large enough) or across multiple work zones as desired.	High	Work zone operations practitioners
Distribution of types of injuries, causes or contributing factors of accidents occurring	Determine frequency of each type of worker accident, divide by the total number of worker accidents in the dataset.	High	Work zone operations practitioners

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5.0 DATA SOURCES AND COMPUTATIONAL METHODS FOR CUSTOMER SATISFACTION-RELATED WORK ZONE PERFORMANCE MEASURES

Most agencies and contractors recognize that the opinions and perceptions of travelers, residents, and businesses are an important component to the successful completion of a highway project. As stewards of significant amounts of public-owned infrastructure and funding, transportation agencies in particular are very sensitive to the opinions of its citizens, and strive to ensure that its customers experience a high degree of satisfaction with the agency.

The delays, congestion, and overall inconveniences caused by work zones can be very challenging to an agency or contractor who desires to maintain good relationships with the travelers, residents, and business owners who are its customers. Therefore, monitoring and measuring customer satisfaction associated with work zones is a critical component to an agency's or contractor's set of useful work zone performance measures

5.1 Customer Satisfaction Data Sources

Agencies and contractors can assess customer satisfaction associated with a particular work zone, or with all work zones in general in a region, along a corridor, or even throughout a city or state. For the most part, methods available to obtain customer satisfaction data are similar for both types of assessments. However, the questions asked and amount of data ultimately needed to establish some level of confidence in the results obtained will differ. In most cases, an agency should work through an institutional review board (IRB) when preparing to obtain customer satisfaction data, as the collection of such data is construed as human subjects research.

5.1.1 Sources that Currently Exist

Sources of Customer Satisfaction Data

- Focus group transcripts
- In-person or telephone interview responses
- Mail, email, or website surveys/questionnaire responses
- Customer complaint database entries

Several methods can be used to obtain either type of customer satisfaction data. The first method, **focus group** studies, consist of a group of people (usually between 6 and 10) who are brought together and asked about their perceptions, opinions, beliefs, and attitudes towards a product, service, or concept. Focus groups can also help aid in establishing questions and anticipated answers for larger questionnaires/surveys. Group participants should be diverse in terms of socio-economic background, age, gender, and education. In some cases, it may be necessary or desirable to evaluate certain traveler groups (commuters, local residents, business owners, transit bus operators, etc.) if concerns exist about certain user group opinions


TTI

Figure 5-1. Focus Group Participants provide their Opinions about Particular Topics and can Offer Ideas on Possible Improvement Needs

In a focus group study, the meeting facilitator engages the participants in open dialog, but keeps them on a script of issues and general questions during the one to two hours that the meetings typically last. Examples of discussion topics might include: problems encountered or noticed in a particular work zone or in work zones in general and thoughts on how a work zone could be improved. In some instances, it will be possible to obtain an overall consensus on a certain topic; in other cases, multiple viewpoints and positions on a topic can exist. Focus groups generally do not involve enough participants to provide statistically significant findings, so their primary value is in the insights gained as participants provide their opinions, experiences, and suggestions to the various questions asked by the facilitator and subsequent discussion that may evolve within the group. Therefore, focus group results should be viewed as anecdotal findings and not as an assessment of the overall driving population within the work zone area.

The next customer satisfaction data available for use by agencies or contractors are **one-on-one interviews**. Such interviews can be done in person or over the telephone. Personal interviews are more appropriate when information pertaining to a particular project is of interest. For example, interviewers may approach potential participants in a public area within or just downstream of a work zone with the intent of gathering data while the driving experience through the work zone is still fresh on the participants mind. Conversely, when interest is on multiple work zones or work zones in general in a given region, such as is illustrated in Figure 5-2, a broader sample base is usually preferred and is more easily obtainable over the telephone.

When interviews focus on a single work zone, it is important to remember that the interview data is reflective of when the interview is conducted. Responses may vary at the same location over time if conditions change. Also, trained interviewers are usually needed to ask and record questions during the interview and assess findings post-discussion. For in-person interviews, the survey needs to be short (3 or 4 questions), as travelers will typically not be inclined to stay and participate for a long period of time. The administration of both in-person and telephone interviews is fairly labor intensive.

Bender, D. and J. Schamber. *SSDOT 2002 Statewide Customer Survey*. Report No. SD2002-07-F. South Dakota Department of Transportation, Pierre, SD. December 2002. Accessible at http://sddot.com/business/research/projects/docs/SD2002_07_Final_Report.pdf.

PART II. DRIVING CONDITIONS

For my next series of questions I'd like you to think about recent highway conditions you have experienced.

14. How often in the past three months have you encountered highway work such as construction or maintenance in South Dakota? Would you say…[READ LIST]
    - Always
    - Almost always
    - Occasionally
    - Very seldom, or
    - Never
    - [DO NOT READ] Don't know

15. Do you think the level of HIGHWAY CONSTRUCTION AND MAINTENANCE this year increased, decreased or stayed about the same as compared to last year?
    - Increased
    - Decreased
    - Stayed about the same
    - Don't know

16. How often do you feel you slow down for highway work zones when there is no visible work being done? Would you say it occurs always, almost always, occasionally, very seldom or never?
    - Always
    - Almost always
    - Occasionally
    - Very seldom, or
    - Never
    - Don't know

17. Do you feel the length of delays caused by highway construction and maintenance this year has increased, decreased, or stayed about the same as compared to last year?
    - Increased
    - Decreased
    - Stayed about the same
    - Don't know

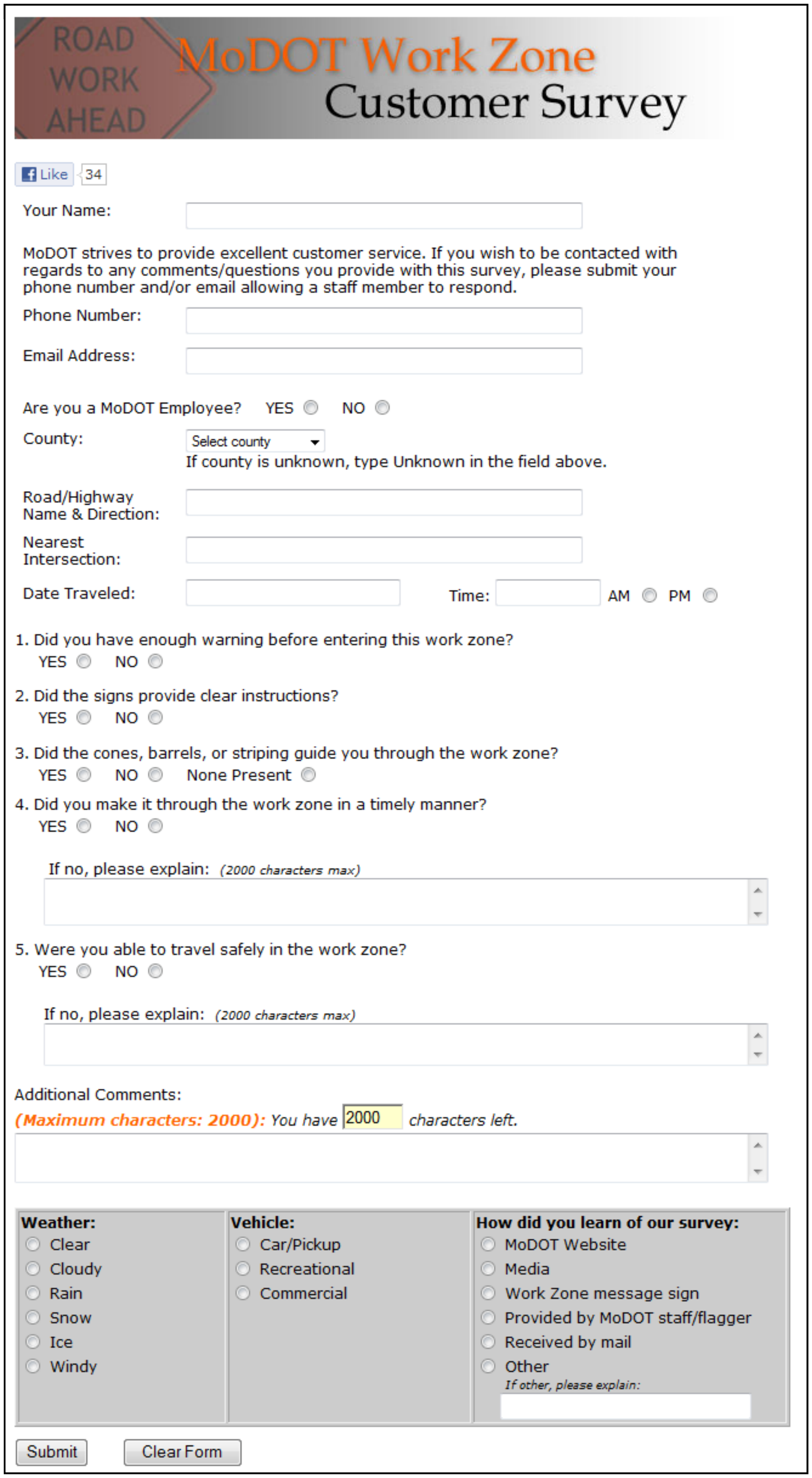
18. Please describe your level of tolerance for the length of delays you generally experience. Using a scale of 1 to 10 where "1" means you really don't mind and "10" means that the delays are intolerable: what number represents how you feel about the length of delays you experienced this past year?

Don't mind								Intolerable		
1	2	3	4	5	6	7	8	9	10	DK

19. Please describe your level of tolerance for the length of time it generally it takes to clear dead animals from roadsides of state highways. Using a scale of 1 to 10 where "1" means you really don't mind and "10" means that the delays are intolerable: what number represents how you feel about the length of delays you experienced this past year?

Don't mind								Intolerable		
1	2	3	4	5	6	7	8	9	10	DK

Figure 5-2. Example of a Script Used during a Telephone Interview of South Dakota Motorists



MoDOT Work Zone
Customer Survey

Like 34

Your Name:

MoDOT strives to provide excellent customer service. If you wish to be contacted with regards to any comments/questions you provide with this survey, please submit your phone number and/or email allowing a staff member to respond.

Phone Number:

Email Address:

Are you a MoDOT Employee? YES NO

County: Select county
If county is unknown, type Unknown in the field above.

Road/Highway Name & Direction:

Nearest Intersection:

Date Traveled: Time: AM PM

1. Did you have enough warning before entering this work zone?
YES NO

2. Did the signs provide clear instructions?
YES NO

3. Did the cones, barrels, or striping guide you through the work zone?
YES NO None Present

4. Did you make it through the work zone in a timely manner?
YES NO

If no, please explain: *(2000 characters max)*

5. Were you able to travel safely in the work zone?
YES NO

If no, please explain: *(2000 characters max)*

Additional Comments:
(Maximum characters: 2000): You have 2000 *characters left.*

Weather:	Vehicle:	How did you learn of our survey:
Clear	Car/Pickup	MoDOT Website
Cloudy	Recreational	Media
Rain	Commercial	Work Zone message sign
Snow		Provided by MoDOT staff/flagger
Ice		Received by mail
Windy		Other
		If other, please explain:

Submit Clear Form

MoDOT Work Zone Customer Survey. Missouri Department of Transportation. Accessible at http://www.modot.mo.gov/workzones/Comments.htm.

Figure 5-3. Agency Websites are a Common Venue Used for Customer Surveys/Questionnaires

Another way that customer satisfaction data can be collected is through **formal customer surveys/ questionnaires** administered through the mail, email, or from an agency or contractor website. Questionnaires/surveys may be designed for quantitative statistical analysis or for qualitative assessment. Generally, responses are limited to predetermined options although there may be an option to provide comments. Surveys can usually be developed to gather enough data to yield statistically significant findings. However, a trained survey designer should be used whenever possible to avoid developing questions and responses that lead or bias the results obtained.

Surveys are often most useful when done periodically to compare responses over time. Survey costs can be high depending on the type of survey and the sample size. If administered via email or through an agency's website, it is important to recognize that there is a potential for selection bias, as younger and more educated travelers tend to be more comfortable with using the internet. It is also important to realize that almost all types of questionnaires and surveys suffer from a slight negative bias. Customers who are unhappy with conditions and have a complaint are more likely to respond than those without problems or complaints.

A fourth source of customer satisfaction data for agencies and contractors is the unsolicited **customer complaints.** Most agencies have a formal process in place to respond to complaints (as do some contractors). However, the availability of the data for work zone performance monitoring and measurement purposes is dependent upon agency documentation practices. Some agencies maintain formal databases to track complaint arrivals and disposition, which can facilitate search and collation of the data for work zone related complaints. Some complaints will be easily associated with a work zone or work zones in a given corridor or region (i.e., complaints regarding the condition of a work zone, closure of a ramp or intersection, etc.). Other complaints, however, may be more indirect. For example, an increase in the number of complaints regarding poor signal timing at an intersection may be due to increased traffic that diverted from a nearby route where a work zone has degraded travel conditions.

Travelers, residents, or nearby businesses may embellish conditions somewhat when making a work zone-related complaint

Customer complaints can be an effective data source for identifying specific operational or safety problems in work zones, and if tracked over time can aid agencies in assessing the effectiveness of their efforts to reduce such complaints. Some agencies (such as the Illinois Tollway) even solicit traveler comments and complaints in its work zones (see Figure 5-4). When taking the time to file a complaint, a driver may embellish the conditions they experienced. Complaints filed are not necessarily indicative of the overall level of driver satisfaction, as those who are not unhappy generally do not contact the agency to indicate their general satisfaction. It may be possible to establish general complaint rates and compare between projects or regions. However, statistical analyzes of such comparisons may not be possible due to small sample sizes.

Best Practices in Work Zone Assessment, Data Collection, and Performance Evaluation. Scan Team Report, NCHRP Domestic Scan 08-04. October 2010. Accessible at http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-68A_08-04.pdf.

Figure 5-4. Illinois Tollway Actively Solicit Input about Work Zones on Its Facilities

5.1.2 Potential Sources in the Near Future

Many agencies (and some contractors) have begun embracing the use of social media technologies, primarily **Facebook** and **Twitter**, to communicate with its customers. Examples already exist of efforts by various state DOTs to disseminate current travel conditions through these venues. A few agencies have begun using these sites as a way to collect customer opinion and satisfaction information. This approach does offer agencies the opportunity to easily "push" questions out to the more technology-savvy portion of its customer base. In addition, it does appear to be a popular way for that group of customers to interact with the agency to ask questions and obtain tailored responses. Concerns about selection biases and similar issues that surround the traditional customer survey techniques will continue to exist with these new approaches as well. Similar to customer complaint sources, social media responses may be skewed more negatively than a representative sample of the entire driving population would reveal. As long as they are used with consideration given to these biases, they can be an extremely useful method of obtaining information about perceived issues and problems.

Another emerging technology with potential use for obtaining customer satisfaction data is the use of **web-based tools to conduct on-line focus group** discussions. These tools are already being used for product testing and placement research (see, for example, http://www.e-focusgroups.com/online.html). Depending on the tool used, capabilities exist to connect participants via web cameras to allow non-verbal interaction among participants. Various parts of the survey screen are assigned to various mechanisms for interacting with the group. For example, the system may allow the facilitator to "poll" the group on various questions, allow for private chat sessions between the facilitator and each of the participants, provide a "groupthink" area where participants can type in various thoughts they have on a topic and allow others to comment (similar to a Facebook post). These tools improve the ability of the facilitator to record the various ideas and statements provided during discussions.

5.1.3 Key Considerations and Trade-Offs of Work Zone Customer Satisfaction Data Sources

A summary of the key considerations and trade-offs associated with customer satisfaction data sources for work zone performance measurement is presented in Table 5-1. As noted previously, most of these require attention to and compliance with federal regulations governing human subjects research.

Table 5-1. Considerations and Trade-Offs of Customer Satisfaction Data Sources

Data Source	Key Considerations and Trade-offs
Focus groups	• Best for gathering opinions, perceptions • A properly trained facilitator is critical • Data from multiple groups may be needed to obtain adequate input from various types of customers
One-on-one interviews	• Best for obtaining responses and input from users during or right after they have passed through a work zone • May need to do surveys multiple times as conditions a the work zone change
Surveys/Questionnaires	• Multiple dissemination mechanisms (mail, email, website) possible • Potential to reach a larger sample size more efficiently • Properly designed surveys with adequate sample sizes can yield statistically significant results
Complaints	• Work zone effects may trigger complaints directly or indirectly • Customers may embellish the magnitude of the problem • Statistical analyses are usually not possible with the data
Social media uses	• Important to rely on trained survey designers for these applications as well • Responses will be biased towards younger, more technology-savvy users
On-line focus groups	• Allows participants to remain at their computers to participate • Although efforts to mimic the interactions that occur in face-to-face focus groups are incorporated into the systems, their effectiveness in doing so is unknown

5.2 Identifying and Computing Specific Customer Satisfaction Performance Measures

Several possible measures to assess customer satisfaction in a work zone or across multiple work zones are presented in Table 5-2. Assessments of the quality and adequacy of specific aspects or features of a work zone or group of work zones was perceived by the expert panel as having a high level of importance or value to the agency or contractor, because it provided targeted guidance on issues to correct or improve. Interestingly, assessments of the quality or satisfaction associated with traveling through a work zone were viewed as only moderately important by the panel. It was noted that such ratings can be heavily influenced by media reports (positively or negatively) and will likely reflect most recent experiences that may or may not be totally attributable to the work zone itself (a major accident occurring in the work zone during the peak period, for example, could bias those customers regarding the overall quality of travel through the work zone in peak periods on most days).

Table 5-2. Examples of Specific Customer Satisfaction Performance Measures

Measure	Computations Required	Value or Importance Ranking	Potential Audience(s)
Ratings of the quality of various work zone features (signs, information provided regarding delays, queues, work activities) seen while driving through a work zone	No computations needed	High	Work zone design practitioners Work zone operations practitioners
Ratings of satisfaction with travel conditions through multiple work zones on a corridor or in a region or network	No computations needed	Moderately High	Work zone design practitioners Work zone operations practitioners
Frequency or rate of complaints	No computations needed	Moderately High	Work zone design practitioners Work zone operations practitioners
Ratings of satisfaction while traveling through work zone	No computations needed	Moderate	Work zone design practitioners Work zone operations practitioners

6.0 DATA SOURCES AND COMPUTATIONAL METHODS FOR AGENCY AND CONTRACTOR WORK ZONE EFFICIENCY AND PRODUCTIVITY PERFORMANCE MEASURES

Methods of tracking work efforts and productivity in the highway construction industry have existed for many years, and have been well integrated into the institutional structures of most agencies and contractors. The primary focus of these efforts has been on ensuring that quality work is being performed efficiently, as well as on providing data that can be used for planning and estimation efforts on future projects. Recently, additional attention has been given to the influence of work productivity and quality upon work zone safety and mobility. Work completed as fast as possible minimizes the exposure of both travelers and work crews to the safety hazards of work zones, and can reduce the total amount of delay and congestion that are attributable to the presence of work zones on a facility. Likewise, construction and maintenance efforts that improve the overall durability of the roadway can reduce the frequency of all types of work zones on the roadway, which also reduces work zone exposure and impacts. Consequently, quantifying both productivity/efficiency and roadway durability and relating them to decisions on construction methods, contracting techniques, and materials used is another important dimension work zone safety and mobility performance measurement.

6.1 Efficiency and Productivity Data Sources

6.1.1 Sources That Already Exist

Existing Sources of Work Zone Productivity and Efficiency Data

- Construction management system database entries
- Lane closure request and approval database entries
- Daily project diary notes

Data collected specifically for a work zone – All agencies maintain some type of electronic construction management system for the various projects being funded. Data from these databases are developed into productivity rates and quantities for various work tasks. These databases are also used to track such things as percent of project funds expended versus amount of work accomplished, percent of projects on time, and so on. Depending on the system, parsing of these data could yield measures that can assess how well a particular strategy to accelerate construction is working. It should be noted that although a construction management database provides an ongoing record of project activity on a section of roadway over time, the duration that such records are kept varies from agency to agency. As a result, it may be necessary to initiate additional data recordkeeping to track such efforts over the long term.

In addition, a construction management database will not include activities that are performed by agency maintenance forces or by utility departments. Some agencies have initiated formal lane closure request and approval processes for certain roadways, regardless of the entity performing the work. Also discussed previously as a source of lane closure exposure data, such data can also be used to assess time between work activities on a roadway segment over time, if all entities performing lane closures have to request permission. An example of such a system that is used by the Illinois Tollway Authority is shown in Figure 6-2 and Figure 6-3.

Virginia Department of Transportation

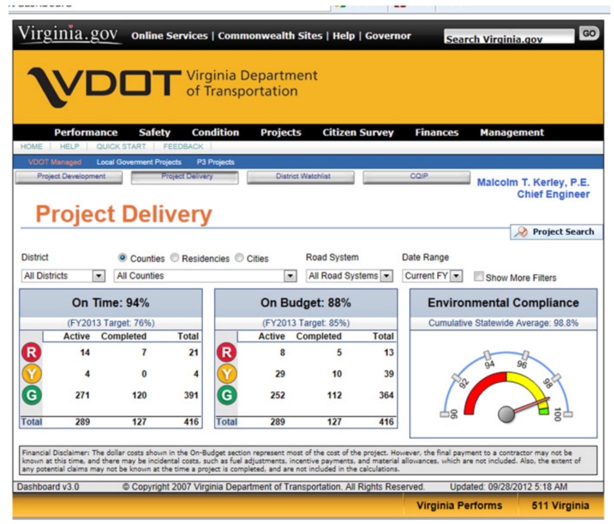


Figure 6-1. Various Construction Performance Metrics are Computed from an Agency's Construction Management Database

Illinois Tollway Presentation to the NCHRP 20-68A Domestic Scan 08-04 Team.
Columbus, Ohio. March 12, 2010

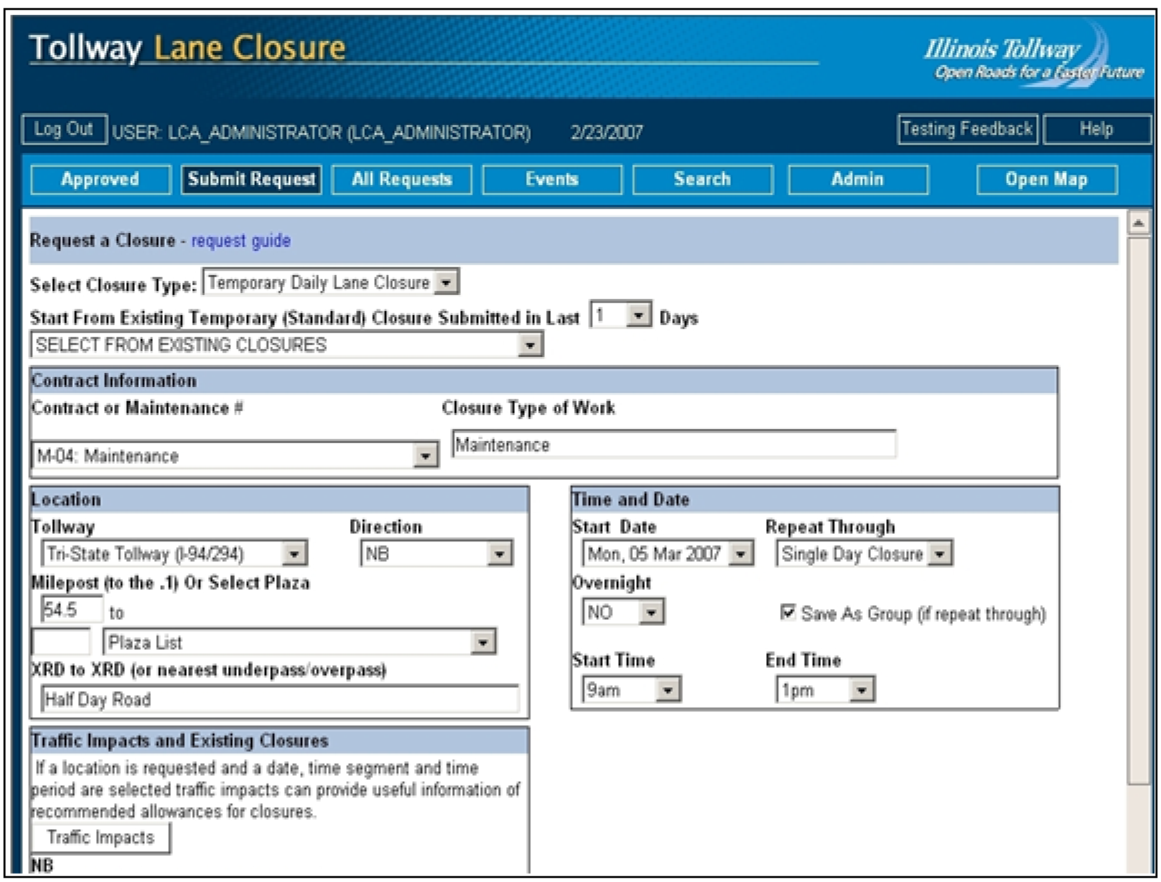


Figure 6-2. Illinois Tollway Lane Closure Entry Screen

Illinois Tollway Presentation to the NCHRP 20-68A Domestic Scan 08-04 Team. Columbus, Ohio. March 12, 2010

TOLLWAY TEMPORARY LANE / SHOULDER CLOSURES

MONDAY - TUESDAY, APRIL 21 - 22 2008

Maint. bldg. or Contract # and Description	MP. DIR & NEAREST CROSSROADS	REASON	Lanes Closed	Lanes Open	HOURS
Monday Night - Tuesday, April 22, 2008		**OVERNIGHT CLOSURE**			
Tri-State Tollway (I-94/294)					
5346: Rdwy/Bridge Widening & Reconst.	18.0 - 18.4 SB: between 95th St & 87th St	Noise Wall Construction	Right Ramp Lane	Left Ramp Lane	8pm - 10pm
5346: Rdwy/Bridge Widening & Reconst.	18.0 - 18.4 SB: between 95th St & 87th St	Noise Wall Construction	Left Ramp Lane	Right Ramp Lane	10pm - 5am
5517: Rdwy Widening & Reconst.	31.1 SB: exit ramp from SB I-294 to WB I-88	Sign Truss Work/Inspection	Right Ramp Lane	Left Ramp Lane	8pm - 5am
M-03: Maintenance	37.7 - 38.2 SB: between Bensenville Bridge & Irving Park Rd	Pavement Repair	2 Left Lanes	2 Right Lanes	11pm - 5am
5242: Rdwy/Bridge Widening & Reconst.	44.7 - 49.0 NB: between Ballard Rd & Willow Rd	Pothole Repair	Right Lane	2 Left Lanes	8pm - 10pm
5242: Rdwy/Bridge Widening & Reconst.	44.7 - 49.0 NB: between Ballard Rd & Willow Rd	Pothole Repair	2 Right Lanes	Left Lane	10pm - 5am
IDOT-60B01: Bridge Widening & Reconst.	55.8 - 61.3 SB: between Duffy Ln & EJ&E RR	Bridge Beam Erection	Left Lane	2 Right Lanes	11pm - 5am
5245: Rdwy Widening & Reconst.	56.2 - 59.0 NB: between Duffy Ln & IL 60	Pavement Repair	Left Lane	2 Right Lanes	8pm - 10pm
5245: Rdwy Widening & Reconst.	56.2 - 59.0 NB: between Duffy Ln & IL 60	Pavement Repair	2 Left Lanes	Right Lane	10pm - 5am
IDOT-60B01: Bridge Widening & Reconst.	59.0 - 59.5 NB: between Everett Rd & Lake Forest Oasis	Bridge Beam Erection	Left Lane	2 Right Lanes	8pm - 5am
IDOT-60B01: Bridge Widening & Reconst.	59.0 - 59.5 SB: between Everett Rd & Lake Forest Oasis	Bridge Beam Erection	Right Lane	2 Left Lanes	8pm - 11pm
IDOT-60B01: Bridge Widening & Reconst.	59.0 - 59.5 SB: between Everett Rd & Lake Forest Oasis	Bridge Beam Erection	Right Lane	Center Lane	11pm - 5am
IDOT-60B01: Bridge Widening & Reconst.	**TEN (10) 15 minute SB FULL CLOSURES with Trooper Assistance at 12:00 AM, 12:30 AM, 1:00 AM, 1:30 AM, 2:00 AM, 2:30 AM, 3:00 AM, 3:30 AM, 4:00 AM, 4:30 AM**			between	Midnight - 5am
5226: Rdwy Widening & Reconst.	62.0 - 62.5 NB: between EJ&E RR & Metra RR	Pavement Repair	2 Right Lanes	Left Lane	11pm - 5am
5226: Rdwy Widening & Reconst.	62.5 - 61.3 SB: between IL 176 & EJ&E RR	Pavement Repair	Right Lane	2 Left Lanes	7pm - 11pm
5228: Rdwy Widening & Reconst.	62.5 - 65.0 NB: between IL 176 & O'Plaine Rd	Pavement Repair	Right Lane	2 Left Lanes	8pm - 11pm
5228: Rdwy Widening & Reconst.	62.5 - 65.0 NB: between IL 176 & O'Plaine Rd	Pavement Repair	2 Right Lanes	Left Lane	11pm - 6am
5228: Rdwy Widening & Reconst.	62.5 - 65.0 NB: between IL 176 & O'Plaine Rd	Pavement Repair	Right Lane	2 Left Lanes	6am - 8am
5224: Bridge Reconstruction	66.9 - 67.3 SB: between O'Plaine Rd & Des Plaines River	Median Work	Left Lane	2 Right Lanes	2am - 6am
M-04: Maintenance	73.4 - 73.5 SB: Wadsworth Rd	Camera Work	All ORT Lanes	All Cash Lanes	Midnight - 4am
Jane Addams Memorial Tollway (I-90)					
9011: Pavement Markings	3.5 - 8.5 EB: between Wolf Rd & Golf Rd	Pavement Striping	Left Lane	2 Right Lanes	8pm - 11pm
9011: Pavement Markings	3.5 - 8.5 EB: between Wolf Rd & Golf Rd	Pavement Striping	2 Left Lanes	Right Lane	11pm - 5am
5540: Rdwy Widening & Reconst.	62.8 - 63.4 WB: between Newburg Rd & Business US 20 Ramp	Barrier Wall Installation	Right Lane	Left Lane	7pm - 7am
5540: Rdwy Widening & Reconst.	66.1 - 70.0 WB: between Spring Creek Rd & Swanson Rd	Pavement Repair	Right Lane	Left Lane	7pm - 7am
5542: Rdwy/Bridge Reconst.	70.0 - 75.5 WB: between IL 173 & S Beloit Plaza	Pothole Repair	Right Lane	Left Lane	7pm - 7am
5542: Rdwy/Bridge Reconst.	73.5 - 75.5 EB: between Burr Oak Rd & S Beloit Plaza	Shoulder Reconstruction	Right Lane	Left Lane	7pm - 7am

Figure 6-3. Illinois Tollway Temporary Lane/Shoulder Closure Database

Information recorded in the daily diary of a project may be another important source of productivity and efficiency data. Hours of certain types of work activities (such as when temporary lane closures are occurring) have been previously discussed as a type of exposure data that can be used to compute other mobility or safety performance metrics (e.g., vehicle-hours of delay per hour of temporary lane closure). However, some of these data can also be used as performance to assess agency or contractor efforts to minimize work zone impacts (e.g., percent of work activity hours that required a temporary lane closure).

6.1.2 Potential Sources in the Near Future

Mobile applications to gather work activity data in the field – Several companies are working on mobile applications to gather work activity directly from field personnel in real time. Although the primary intent of the technology is to improve accuracy of the data entered (many of the applications are based in part on a geographic information system [GIS] platform) and drastically reduce work load involved with manually entering data into a construction management system, additional development work could facilitate easier and more systematic entry of data directly relevant to work zone safety and mobility performance measurement. For instance, field identification of work locations for each shift, any road or lane closure information (locations, number of lanes closed, start and end times) could be very easily recorded on a mobile device and stored in the database.

Electronic database of agency maintenance work – Many agencies do certain types of work with its own forces out of its area offices or maintenance yards. These activities generally are tracked by type of work task completed and location in some type of daily work diary to assist in assigning staff time to various accounts, but these data are not generally coded into any type of database that is tied to roadway locations. However, a few agencies are beginning to recognize the value of tracking these maintenance efforts, and have developed maintenance management systems that in many ways mimic those of the traditional construction management databases.

6.1.3 Key Considerations and Trade-Offs of Work Zone Efficiency and Productivity Data Sources

Table 6-1 provide a summary of some of the key considerations and trade-offs associated with the various construction productivity and efficiency data sources. Although mobile applications for field entry of project activities do currently exist, collection of MOT data of interest for work zone safety and mobility performance measurement can be recorded in these applications will depend on whether the underlying database being populated (i.e., the construction management database) has field structures and elements that allow the data to be input from the mobile device.

Table 6-1. Considerations and Trade-Offs of Construction Productivity and Efficiency Data Sources

Data Source	Key Considerations and Trade-offs
Construction management system databases	• Focus of most systems is still mainly on contract-related data (quantities, task completion levels) • Many of the MOT data elements of interest are entered via narratives into the system, with minimal consistency in entries across projects
Lane closure request and approval databases	• May include closures across all agencies and contractors in a region • Will normally be limited to high-volume roadways only • Depending on administrative processes established, the database may contain a large number of "phantom" closures that need to be removed prior to analyses
Daily project diaries	• MOT data entered (if any) often varies significantly from project to project
Mobile applications for field entry of project activities	• Requires field personnel to carry and use mobile devices in the field (costs and durability of the devices may become an issue) • An application of this type may not yet exist
Maintenance management system databases for agency staff	• Requires detailed recordkeeping of activities by all maintenance crews and crew members

6.2 Identifying and Computing Specific Work Zone Efficiency and Productivity Measures

Table 6-2 presents four types of construction productivity and efficiency-related performance measures that could be useful for work zone safety and mobility performance measurement. Level of activity, expressed as a percentage of possible days that could be worked, was cited as a high priority measures by the expert panel that reviewed and rated the measures. A measure of compliance with agency-established MOT criteria (i.e., the percent of lane closure hours occurring outside of accepted work windows) was also cited as a high-priority measure. Various types of traditional construction productivity measures that could be stratified based on roadway type, type of MOT used, construction methods used, etc. was considered a moderately-high priority. The panel also rated one specific type of construction method, the percentage of activities involving a temporary lane closure, as a moderate priority measure, due to its direct relevance to operating conditions and safety of the traveling public. Finally, a measure of average time between work efforts on a given roadway segment was not specifically rated by the panel, but was included in the table as a way to encourage the long term tracking of such work efforts by agencies and contractors in the future.

Table 6-2. Examples of Specific Agency or Contractor Efficiency and Productivity Performance Measures

Measure	Computations Required	Value or Importance Ranking	Potential Audience(s)
Percent of allowable or total days worked	Determine the actual number of days worked and divide by the total number of to date (either the allowable work days or calendar days)	High	Work zone design practitioners Work zone operations practitioners
Percent of lane closure hours occurring outside established "work windows"	Determine total amount of lane closure hours occurring outside of accepted time work windows, divide by the total number of lane closure hours that have been worked (this should be a very low percentage)	High	Work zone design practitioners Work zone operations practitioners
Typical work productivity measures stratified by type of project MOT, construction acceleration technique employed, etc.	Average productivity measures of interest across multiple projects having the same MOT in place, using the same type of construction acceleration technique, etc.	Moderately High	Work zone design practitioners Work zone operations practitioners
Average hours worked during work activities involving temporary lane closures, possibly stratified by time of day, weekday versus weekend	Determine total hours of work activities that involve temporary lane closures, divide by the total hours of work activity overall or for specific time periods of interest	Moderate	Work zone design practitioners Work zone operations practitioners
Average time between work zone activity, possibly by type of work being accomplished, construction methods used, etc.	The frequency of work efforts (construction, maintenance, or utility) over time on a roadway segment, divided by the total time that such activities were tracked	Not rated	Work zone design practitioners

7.0 REFERENCES

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Appendix A.

Delphi Survey Methodology to Prioritize Work Zone Performance Measures

DELPHI SURVEY METHODOLOGY TO PRIORITIZE WORK ZONE PERFORMANCE MEASURES

The Delphi Survey Method is a systems analysis technique designed to allow individuals to converge on opinions, ratings, priorities, etc. without having to be in face-to-face or video/teleconference communications. In fact, opinions of individuals are kept anonymous so as to avoid creating any biases in the data. The Delphi process itself works best with a limited number of participants, and so the research team, in consultation with FHWA, reached out to 10 practitioners to participate as an advisory panel for the project and assist in the Delphi survey process. Five of the panel participants were state work zone traffic control engineers or equivalent, two were from research institutions and had both performance measurement and work zone safety and mobility backgrounds and expertise, two others were private-sector consultants with performance measurement backgrounds and expertise, and the final panelist was a city traffic engineer from a moderate-sized city on the west coast. For this project, an initial on-line survey instrument was created to obtain initial panel member ratings of the various work zone performance measures and measurement categories, and to provide any thoughts on additional measures or categories that could prove useful to agencies and other practitioners for evaluating and monitoring work zone safety and mobility impacts. The survey is included as Appendix A. Each participant was asked to consider each proposed performance measure in terms of its importance or value they would place upon it (assuming the measure accurately reflected the data upon which it was calculated). Panelists rated each measure on a scale from 1 to 5, with a "1" indicating that they considered the measure to be of low importance, and a "5" indicating that they considered the measure to be of high importance. Any comments they wished to offer in terms of their thought processes were welcomed as well.

Once the initial ratings were obtained, researchers computed the median rating value, and both the 25th and 75th percentile rating values submitted. The median (50th percentile) value was where one-half (5) of the panelists rated the measure higher, and one-half rated it lower. The 25th and 75th percentile rating values were calculated in a similar manner. If all panelists gave the measure the same rating value, the 25th, median, and 75th percentile value would be the same.

All ratings that fell in this range were judged to indicate general agreement with the median rating value, whereas values outside of that range were considered to not be in general agreement. A second iteration of the survey was then developed that was tailored to each individual panel member. The panelist received a reminder of their initial rating value for that measure or category, the median value given by the overall panel, and a notice if their rating did not fall within the inter-quartile range for the group (i.e., the value was an outlier). The panel member then decided if they wanted to change their rating value to something within the inter-quartile range, or keep the rating outside the range and provide a justification for their rating value (i.e., why they rated the measure or category higher or lower than the group). This was repeated a third time so that everyone could see the justifications provided and offered a chance to change their ratings as well.

Overall, the process worked extremely well, with the median rating values stabilizing after the second iteration, and the inter-quartile ranges for almost all of the measures and categories decreasing dramatically between the first and second iterations. Only a few final changes occurred during the third iteration of the survey, which had no effect on the median values and small reduction in inter-quartile ratings for a few of the measures and categories.

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