A PRIMER ON WORK ZONE SAFETY AND MOBILITY PERFORMANCE MEASUREMENT

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16. Abstract

This primer has been developed to assist agencies in establishing and monitoring a useful set of work zone safety and mobility performance measures. Work zone performance measures are metrics that help to quantify how work zones impact travelers, residents, businesses and workers. Work zone performance measures help agencies improve their understanding of how their decisions during planning, design, and construction affect work zone safety and mobility, and thus can help improve how they make decisions for future work zones.

The primer describes possible work zone performance measures, and provides guidance to help agencies select and implement measures that make sense for their own work zone programs. The primer outlines the methods and technologies that are available to gather data to monitor the various possible measures and procedures for calculating specific performance measures from different types of work zone traffic monitoring data. The primer also discusses the use of measures across multiple projects to assess an agency's overall efforts and outcomes against its policies and goals.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Work zone performance measures are metrics that help to quantify how work zones impact travelers, residents, businesses and workers. Some measures describe the impacts of a specific work zone (project-level metrics), whereas other measures describe the impacts of a set of work zones (agency program-level metrics). What is expected to occur at a work zone with regard to safety or mobility impacts can be quite different from what is ultimately experienced at a site. Every work zone is unique, and the combined effects of design decisions, work phasing and sequencing operations, and impact mitigation strategies implemented at a site can be challenging to predict beforehand. Work zone performance measures help agencies improve their understanding of how their decisions during planning, design, and construction affect work zone safety and mobility, and thus can help improve how they make decisions for future work zones.

Work zone performance measurement does not need to be an overwhelming activity for an agency. Not all work zones need to be measured, and those work zones that are measured do not necessarily need to be monitored at all times. Work zone performance measurement should be driven by agency and other stakeholder needs and priorities. One advantage of establishing work zone performance measures is that it focuses attention on what is considered important to the agency and stakeholders.

To be useful, it is important for agency staff to understand:

- What is being measured,
- How it is being measured, and
- Why it is being measured.

Efforts to improve work zone policies, processes, and procedures will be more effective if agencies also look at measures across multiple projects to assess their overall efforts and outcomes. Tracking how often an agency meets its performance expectations for work zone safety and mobility across multiple work zones can be more indicative of overall performance and useful as program-level performance measures.

Agencies should choose a few good measures carefully based on their particular needs and characteristics, communicate those to all stakeholders and staff, and track them clearly, seriously, and consistently. Three basic types of performance measures are useful to quantify work zone safety and mobility impacts:

- Exposure measures,
- Safety measures, and
- Mobility (traffic operations) measures.

Exposure measures describe the amount of time, roadway space, and/or vehicle travel that a work zone or a collection of work zones affects or requires. Safety measures describe how crash risk has changed for the individual motorist and/or for the traveling public in general, relative to pre-work zone levels. Safety measures can also be defined for contractor or agency personnel working on the roadway. Finally, mobility (traffic operations) measures describe how travel mobility has been affected for motorists (and potentially other types of travelers as well).

Work zone performance measures should:

- Relate to the safety and mobility goals and objectives that the agency has established for itself,
- Be consistent with the measures used in impact assessment efforts for work zone planning and design analyses,
- Characterize the different facets of impacts that are occurring,
- Enable the agency to evaluate the effects of alternative strategies for mitigating traffic impacts caused by work zones, and
- Be compatible with other performance measures that an agency is using to evaluate its system.

Once work zone performance measures have been selected, agencies need to define the data sources, collection techniques, and calculation methodologies that will be used to compute those measures. For some measures, only one data source and/or methodology will exist for an agency; for others, several sources and methodologies may be available. Agencies must balance the data needs for performance measures with available resources and other factors to determine the most appropriate sources or methodologies to use.

INTRODUCTION

Work zones can cause significant traffic congestion and safety impacts. Agencies strive to manage these impacts as best possible so as to meet the needs of its customers, complete the project effectively, and support regional mobility and economy. On September 9, 2004, the Federal Highway Administration (FHWA) amended its regulation (23 CFR Part 630 Subpart J) that governs traffic safety and mobility in highway and street work zones (*1*). One provision in the rule requires states to use both traffic safety and operational data to help improve agency processes and procedures to address work zone impacts. Specifically, states are encouraged to develop and implement systematic procedures that assess work zone impacts in project development, and to manage traffic safety and mobility impacts during project implementation. One way that agencies can improve these efforts is through the use of performance measures.

WHAT ARE WORK ZONE TRAFFIC SAFETY AND MOBILITY PERFORMANCE MEASURES?

Work zone performance measures are metrics that help to quantify how work zones impact travelers, residents, businesses and workers. Some measures describe the impacts of a specific work zone (project-level metrics), whereas other measures describe the impacts of a set of work zones (agency program-level metrics). Some examples of possible work zone performance measures include:

- The average peak-period delay to vehicles entering a work zone,
- The percent of time that a work zone queue exceeds an agency-established allowable threshold,
- The average percent increase in crashes in freeway work zones in a given state, and
- The number of injury crashes occurring during temporary lane closures on particular types of roadways.

WHY SHOULD WORK ZONE PERFORMANCE MEASURES BE USED?

Safety or mobility impacts predicted for a work zone during planning and design can be quite different from what is ultimately experienced at a site. Every work zone is unique, and the combined effects of design decisions, work phasing and sequencing operations, and impact mitigation strategies implemented at a site can be challenging to predict beforehand. Work zone performance measures help agencies understand how their decisions affect work zone safety and mobility. This allows agencies to improve conditions at current work zones as well improve how they make decisions for future work zones.

Work zone traffic safety and mobility performance measures have a variety of other uses to state departments of transportation (DOTs) and other highway agencies. Specifically, performance measures allow agencies to:

- Assess whether they are meeting their own goals and objectives regarding acceptable work zone traffic impacts;
- Identify specific problems or issues that may be occurring at a particular work zone;
- Review and improve their work zone policies and procedures;
- Review and improve the accuracy of traffic impact assessment tools being used during work zone planning and design;
- Improve the prediction of expected benefits of impact mitigation strategies that may be included in the transportation management plan (TMP) of a project; and
- Better "tell their story" about work zone impacts, and effects of mitigation strategies implemented to reduce those impacts, to elected officials and to the public.

Work zone performance measurement need not be an overwhelming activity for an agency. Rather, agencies should choose a few good measures carefully based on their particular needs and characteristics, communicate those to all stakeholders and staff, and track them clearly, seriously, and consistently.

HOW CAN WORK ZONE PERFORMANCE BE MEASURED?

Not all work zones need to be measured, and those work zones that are measured do not necessarily need to be monitored at all times. Work zone performance measurement should be driven by agency and other stakeholder needs and priorities. One advantage of establishing work zone performance measures is that it focuses attention on what is considered important to the agency and stakeholders.

To be useful, it is important is for agency staff to understand:

- What is being measured,
- How it is being measured, and
- Why it is being measured.

Ultimately, an agency may begin work zone performance measurement efforts on a limited basis by focusing on a few key performance measures for only a few projects each year. Then, as agency staff becomes more familiar with how and why work zone performance measures are used, the number and types of measures examined and the projects included in the analysis can be expanded.

Work zone safety and mobility performance measurement efforts can evolve over time as agency staff becomes more proficient in computing and interpreting the measures of interest.

Three basic types of performance measures are useful to quantify work zone safety and mobility impacts:

- Exposure measures,
- Safety measures, and
- Mobility (traffic operations) measures.

Exposure measures describe the amount of time, work activity periods, roadway space, and/or vehicle travel that a work zone or a collection of work zones affects or requires. Exposure measures are also usually needed as a denominator for safety or mobility performance measures (such as the number of crashes per million-vehicle-miles of travel through a work zone). Both output and outcome exposure measures of performance can be useful. Output-based measures describe the amount of effort or other resources being expended (such as the number of hours of temporary lane closures a contractor has implemented at a project), whereas outcome-based measures describe how many vehicles or vehicle-miles of travel occur through a work zone or group of work zones.

As the name implies, **safety measures** describe how crash risk has changed for the individual motorist and/or for the traveling public in general, relative to pre-work zone levels. Safety measures can also be defined for contractor or agency personnel working on the roadway. Most safety measures are outcome based, such as the increase in injury crashes or the change in overall vehicle crash costs in a work zone. However, a few agencies do track output-based measures of certain efforts to reduce crashes as surrogates to safety impacts, with the assumption that such efforts result in improved safety. An example of such a measure would be the hours of additional law enforcement assigned to work zones in an agency's jurisdiction.

Finally, **mobility (traffic operations) measures** describe how travel mobility has been affected for motorists (and potentially other types of travelers as well). Travel delays caused by work zones are an obvious example of this type of performance measure. However, other measures related to, or correlated with, delay are also available. For example, queue length and duration is a performance measure used by some agencies. Other agencies use average speed through the work zone as a measure. Most traffic operations measures are outcome-based. However, output measures of efforts to reduce delays and queues might also be important to an agency.

Often, the safety and mobility data are combined with exposure data into other performance measures, such as the number of traffic crashes that occur per million vehicle miles of travel in a work zone. This process allows agencies to compare safety and mobility impacts across projects and over time, and also to aggregate those impacts across multiple projects. In other cases, additional computations and analyses may be required to obtain useful performance measures. An example of such analyses is when data is collected on the length and duration of queue lengths at a work zone, and the agency is interested in knowing how these queues translate into vehicle delays through the work zone.

OBJECTIVE OF THIS PRIMER

This primer has been developed to assist agencies in establishing and monitoring a useful set of work zone safety and mobility performance measures. The primer includes guidance on both project-level and agency program-level performance measure needs, defines a number of possible work zone performance measures that agencies can use, and describes the methods and technologies that are available to gather data to monitor them. The primer also outlines procedures on how to calculate specific performance measures from different types of work zone traffic monitoring data, and on use of the measures across multiple projects to assess compliance to agency policies and goals.

Much of the information presented in this primer was based on pilot study research of work zone performance measures for projects in several states nationally. Multiple methods of collecting traffic operations data and computing performance measures from the data were used simultaneously at each project in the study. This simultaneous analysis allowed a comparison of the relative level of effort and precision of performance measures obtained from each data collection method. The reader is encouraged to review the final report of that pilot study effort for additional insights into work zone traffic safety and mobility performance measurement (*2*). In addition, this primer contains information from a recent scan of state DOT best practices for work zone impact assessment, data collection, and performance measurement (*3*).

WORK ZONE PERFORMANCE MEASURE NEEDS

Conceptually, an agency can select from a wide range of potential measures for monitoring work zone safety and mobility performance. Examples of safety measures being used by some agencies include (*3*):

- Crash statistics (frequencies, rates, and types; injuries and fatalities),
- Frequency of work zone intrusions,
- Speeds and speed variance,
- Percent of motorists exceeding the speed limit,
- Speeding citations issued,
- Service patrol or fire department dispatch frequency,
- Work zone inspection scores, and
- Worker fatalities and injuries.

Meanwhile, work zone mobility measures in use by certain agencies include:

- Delay,
- Queue length,
- Queue duration,
- Speeds,
- Volume-to-capacity ratio,
- Level of service,
- Volume (throughput),
- Percent of time operating at free-flow speed, and
- Percent of work zones meeting expectations for traffic flow.

For many of the safety and mobility measures listed, some exposure data and performance measure needs are also implied. Examples of exposure measures that have been used by agencies to normalize safety and/or mobility performance measures in work zones or to describe the amount of mitigation effort expended include:

- Vehicle-miles-travelled through the work zone,
- Number of vehicles passing through the work zone,
- Number of hours of work activity, and
- Hours of dedicated enforcement in the work zone.

Finally, some measures can actually cut across multiple categories. For example, user costs can be computed from the delay and crash data as another type of performance measure (*4*). Likewise, customer surveys and complaints, although more commonly considered an indication of work zone mobility, may actually be influenced by both safety and mobility concerns.

PROJECT- LEVEL PERFORMANCE MEASURE NEEDS

An agency should begin the process of selecting work zone performance measures by examining its current goals, objectives, and thresholds of acceptability for work zone performance. Performance measures are desired which can be easily compared to those goals, objectives, and thresholds to see how well the agency is meeting these criteria. Agencies should also consider the types of traffic impacts analyses it performs during work zone planning and design. In many agencies, one or two impact assessment tools are used for most analyses because agency staff is most familiar with those tools (*3*). One of the uses of work zone performance measures is to evaluate how well work zone impact assessments of planning and design decisions reflect what actually happens once the work zone is implemented in the field.

Not all work zones are created equal. One project may require just a few work activity periods that create intense delays (with several other work periods of no impacts to motorists), whereas another project may have a comparatively small, but consistent delay to motorists throughout the duration of the project. Both projects may thus generate the same amount of total delay overall, but would likely be perceived quite differently by the public. Therefore, agencies will typically also need to select more than one performance measure in each category to fully capture all facets of the impacts that are occurring.

With few exceptions, agencies have the option of choosing:

- When work should occur on a particular roadway,
- How much of the roadway to allocate to the work and how much to leave for traffic to use ,
- What construction strategies and techniques to use, and
- What techniques or strategies to use to mitigate the impacts of the work zone and improve roadway capacity, safety, traffic flow, etc.

The performance measures selected should allow agencies to assess the effectiveness of these types of decisions as well. It may be desirable to establish separate performance measures for different project phases, work operations, time periods during the day or night, or other criteria in order to better assess the ramifications of the decisions that were made. Depending on the measures selected, it may be necessary to obtain data during a few key days or weeks in an overall project (e.g., the first week of each phase change), rather than have to collect a large amount of data over the entire duration of a project. By being targeted and selective, an agency can maximize the effectiveness of its efforts to monitor and evaluate work zone performance.

Finally, some agencies have begun to monitor and track congestion and travel time reliability measures on an ongoing basis on certain roadways in its jurisdiction. Selected work zone performance measures should be compatible with other traffic-related performance measures the agency is using to evaluate overall operations.

Performance measures should:

- ✓ ***Relate to the safety and mobility goals and objectives that the agency has established for itself;***
- ✓ ***Be consistent with the measures used in impact assessment efforts for work zone planning and design analyses;***
- ✓ ***Enable the agency to fully characterize the different facets of impacts that are occurring;***
- ✓ ***Enable the agency to evaluate the effects of alternative strategies for mitigating traffic impacts caused by work zones; and***
- ✓ ***Be compatible with other performance measures that an agency is using to evaluate its system.***

AGENCY PROGRAM- LEVEL PERFORMANCE MEASURE NEEDS

Performance measurement begins at the project level, since that is where the impacts the agency is trying to manage occur. However, not meeting agency-established goals and objectives on a single project may not be indicative of an overall performance issue. Agency efforts to improve its policies, processes, and procedures (as required by the Work Zone Safety and Mobility Rule (*1*)) will be enhanced if impacts are ultimately aggregated and interpreted across multiple projects.

One of the major challenges that agencies face is how to properly aggregate the performance measures computed for individual projects so that useful assessments across multiple projects can be made. For example, should an agency compute an average increase in crash rates across all work zones it has monitored, or compute separate averages for each type of roadway on which the work zones were located? Should the number of projects where queue length thresholds were exceeded be summed together, or should they be counted based on the type of work that was being performed (resurfacing, pavement rehabilitation, roadway widening)?

Many factors will influence the magnitude of work zone safety and mobility impacts that occur. Site characteristics, traffic volumes, and amount of truck traffic are just some examples. However, in terms of items under direct agency or contractor control, two main categories of decisions or actions exist:

- Type of work being performed (and how it is accomplished), and
- Traffic management approach used.

Agency program-level performance measures that are developed around these main categories will likely serve as a useful starting point for policy and procedure reviews.

As was recommended for developing project-level measures, agencies may be best served by taking an incremental, iterative approach. For example, an agency might initially target work zones that involve either long-term or regular short-term lane closures on its freeway facilities, and focus efforts on developing and interpreting performance measures from that set of projects. As the agency develops an understanding of the measures and makes improvements to its processes pertaining to freeway work zones, the agency may begin to monitor and assess work zones on major urban arterial roadways. Eventually, work zones on two-lane highways could be added as well. For some measures, such as fatal crashes, an agency may track the measure across all of its work zones as one measure of overall work zone safety. For other measures, such as delay, an agency may sample a portion of its work zones as this may provide a sufficient indication of whether congestion estimates during planning and design and management efforts during construction are working.

Regardless of how an agency chooses to implement work zone performance measures into its regular program review process, the intent should be to collectively assess how well the work zones being tracked meet the policies and objectives the agency has established. This can often be most easily achieved by developing rates across multiple projects under the agency's jurisdiction for how often the agency's policy goals and objectives are being met. This does not necessarily involve the monitoring or collection and processing of large amounts of data on all projects. Agencies typically have a good idea of which projects will not induce significant impacts, and those which will. In addition, those projects may only experience them during certain phases or work tasks. By focusing their efforts on key times, agencies can keep work zone performance monitoring and evaluation to a manageable level.

Compliance rates across multiple work zones to agency-established work zone safety and mobility objectives are useful program-level performance measures.

SELECTING USEFUL WORK ZONE PERFORMANCE MEASURES

In this section, several possible performance measures are described that can be useful for monitoring and characterizing safety and mobility impacts at highway work zones. The value of these measures is described, along with key considerations in obtaining and monitoring them.

EXPOSURE PERFORMANCE MEASURES

Table 1 presents a list of possible performance measures pertaining to work zone exposure. Exposure measures describing vehicle throughput and miles of travel through work zones can be valuable for establishing safety and mobility rate-based measures as well as for tracking motorist diversion decisions. One of the challenges in using vehicle-miles-travelled as an exposure measure is in defining what length or limits should be used in the computations. For major roadway rehabilitation and reconstruction projects, temporary geometric changes and traffic control features throughout the work zone may suggest that project limits be used for estimating vehicle miles traveled (VMT) of exposure. For other projects, though, vehicle exposure during the times when temporary lane closures are occurring (such as during hours of a hot-mix asphalt overlay job) may be the exposure numbers of interest. In this case, the length of actual lane closures each day or night, rather than the total length of the project, is likely to be a more useful exposure measure.

Exposure measures for tracking contractor activity and efficiency, as well as the amount of roadway space closed to traffic because of work zones, can also be useful for agencies. Examples of these types of measures include the percent of days (or nights) when work activity is occurring, the average number of work activity hours per day (or night), and the percent of work hours when one or more lanes are temporarily closed. Actions taken, or technologies used, to improve safety or operations by an agency can also be measured as illustrated below (this list is not exhaustive):

- The number or percent of projects using portable concrete barrier to protect work spaces and/or pavement drop-offs,
- The number or percent of projects where the agency employed a reduced speed limit (possibly stratified by the amount of speed limit reduction), and
- The number or percent of projects where work zone intelligent transportation system technology was used.

Table 1. Potential Exposure Measures

Measure	Why It is Important	Considerations in Using It
Vehicles passing through the work zone, possibly stratified by work activity or lane closure hours.	Required to compute other performance measures on a per vehicle basis.	Work zones with significant diversion require continuous counts in order to be accurate.
% change in vehicles passing through the work zone	Can represent traffic diverting from the work zone due to public information or other strategies	Requires continuous counts in order to be accurate.
Vehicle-miles-of travel through the work zone, possibly stratified by work activity/inactivity periods and /or lane closure times.	Standard measure of exposure for safety assessments	For some projects, total project length may be the appropriate length to use; for other projects, the length of each lane closure may be more appropriate for computing vehicle-miles-traveled of exposure.
% of days or nights when work activity occurs.	Describes intensity of effort being made to complete the job	Some projects are based on total calendar days, while other projects restrict when work can occur and should consider only the allowable work days/nights.
Average hours of work per day or night.	Useful for assessing contractor utilization of time windows allowed for work	Overlap of subcontractor work efforts on complex jobs can make it difficult to define an overall start and end time each day or night.
% work activity hours with (1,2,3, etc.) lanes closed	Allows queue and delay measures to be stratified by amount of roadway capacity reduction involved	Lanes are sometimes closed in sequence over the course of a work shift (especially at night). It can be difficult to accurately capture these data in detail.
Average lane closure length	Useful for evaluating compliance to maximum lane closure length specifications (if included in contract). Also, useful for extrapolating to similar projects that are not being monitored as closely.	Lane closure lengths can change significantly during a shift as additional lanes are closed (especially at night).
Lane-mile-hours of closures	May be useful in explaining high levels of delay or crash rate increases at certain projects	This measure is less intuitive than other measures.
Number or % of projects employing certain types of strategies or technologies to reduce safety or mobility impacts	It is a program-level measure of agency efforts to improve safety or mobility	Decisions to implement these are typically site specific. It may be necessary to stratify the measures by type of facility, type of work, or other site characteristics in order to be meaningful to the agency.

SAFETY PERFORMANCE MEASURES

Table 2 lists several work zone safety-related performance measures that agencies can use. Many states currently track overall work zone fatalities and injuries statewide on an annual basis. This approach provides a program-level indication of the safety impacts in work zones statewide, and is tracked over time to observe trends in crash frequency over time.

The Ohio DOT compares the total number of work zone crashes that occur statewide each year to the annual amount of construction dollars that were let in that year (3).

The percent of work zone crashes by manner of collision or other crash characteristics is a common type of performance measure used by agencies to identify potential problem areas for countermeasure emphasis. These types of measures are dependent upon differences in traffic volumes and other factors from project to project (*5*). Consequently, examination of these types of measures at a program level (for all work zone crashes in the state, for example) can yield different conclusions from year to year as the characteristics of the projects changes each year.

A recent NCHRP study found that the crash risks to motorists at freeway work zones varied by time of day (daytime, nighttime) as well as by presence of work activity and or the temporary closure of travel lanes (5). The percent of crashes that involved rear-end collisions also varied by these factors as well as the annual average daily traffic (AADT) of the roadway where the work zone was located.

Table 2 also lists changes in work zone crash rates (or crash costs) as a potential safety performance measure. The use of crash rates reduces the effects of differences in exposure and other external factors between projects and allows for a more accurate assessment of work zone safety by the agency. The crash rate per million-vehicle-miles-traveled (MVMT) is a commonly-used measure, and can be stratified by crash severity (injury crashes per MVMT) or other crash characteristic. Other exposure measures can be used as well (e.g., crashes per hour of work activity). Program-level evaluation of agency safety policies and procedures will be best accomplished through crash rate measures.

Table 2. Potential Safety Measures

Measure	Why It is Important	Considerations in Using It
Number of crashes per year or per project: - Fatal - Injury - PDO	Actual crash counts represent the direct effects of work zones on safety.	Crash counts are dependent upon exposure (volumes, work zone length, and work hours at the project level; number of projects at the program level). Changes in funding from year to year could influence exposure and thus program level work zone crash counts.
% Crashes of certain types such as manner of collision (e.g., rear-end crashes), contributing factors (e.g., DWI crashes)	Agency priorities for countermeasure implementation are often linked to the major contributors of work zone crashes.	Percentages of various crash types can also be affected by exposure.
% Change in crash rate or absolute change from the expected no-work zone crash rate; possibly stratified by roadway, work zone type, severity	Changes in crash rates account for key differences in exposure that may also affect crash frequencies, thereby improving the comparability of the measure between sites.	This measure is computed for each individual project of interest; it requires information on exposure before and during each work zone
% of projects that exceed an acceptable crash rate in the work zone	A program-level measure to evaluate compliance with agency-established policies or targets	A reasonable number of projects must be evaluated for this to be meaningful to agencies. It can create substantial workload for the agency, especially if different roadway and project types are to be evaluated separately.
% Change in work zone crash costs from the expected no-work zone crash costs	Crash costs combine frequency and severity together in one measure. Results from multiple projects could be combined for program-level analysis by the agency.	This measure is also computed for each individual project of interest; it requires information on exposure before and during each work zone.
Number of highway worker injuries or worker injury rate per hours worked	Workers are a particularly vulnerable population in work zones.	Obtaining worker injury data from contractors can be difficult. The use of rates will require data on hours of worker exposure.

Measure	Why It is Important	Considerations in Using It
Work zone inspection scores	Work zone inspections or reviews are under the control of the agency. This can simplify data collection and analysis.	Compliance to agency inspection standards is believed to be correlated to improved work zone safety, but research has not yet validated this.
Number of work zone inspections performed	The number of inspections is a program-level measure that agencies can use in conjunction with other safety measures to assess current policies and procedures.	Same as above.
Frequency or change in frequency of service patrol or fire department dispatches to a work zone	Crashes (especially severe crashes) will involve emergency responders. Agency access to this type of data can be faster than access to crash data.	Interagency agreements may be needed in order to obtain the data. For service patrols, non-crash event dispatches (stalls, motorist assistance with fuel, debris in road) may need to be excluded from the dataset to have a meaningful work zone measure.

The use of crash costs allows an agency to incorporate the effects of both crash frequencies and crash severities into a single measure. It is possible, for example, for the number of property-damage-only (PDO) crashes to increase in a work zone (relative to a no-work zone condition) and the number of injury crashes to decrease slightly because of slower speeds through the work zone. The combined effect of those changes can be captured in the change in crash costs. Given that most states have a minimum damage cost reporting threshold for PDO crashes, increases in very minor crashes will not be captured in this measure, however.

Highway worker injuries or injury rates are another potentially useful work zone safety performance measure. Most agencies already track injuries of their own employees, although not always distinguishing between injuries that are traffic related and those that are work related. Basic information on non-agency highway worker injuries can be obtained through the Bureau of Labor Statistics (BLS) database (*6*).

Many agencies perform regular inspections or reviews of work zones under their jurisdiction. Standardizing the review forms and assessment criteria has allowed some state DOTs to establish safety performance measures using these data. Both project-level rating scores and program-level percentages of projects meeting agency-established score thresholds can be established (*3*). In the absence of a formal rating system, other agencies will typically track the number of project inspections or reviews done as a type of work zone safety performance measure.

The New York State DOT assigns a rating score to each of a number of inspection criteria during each project review performed. All projects not meeting agency performance goals are targeted for immediate remedial action by project staff. The agency also evaluates the percentage of projects that meet its rating goals each year. For the past four years, approximately 85 percent of projects evaluated have met their goals (3).

Timely access to crash data is a problem that many agencies face when attempting to measure work zone safety performance. At least one agency has attempted to circumvent this problem by examining service patrol and fire department dispatch frequency to locations within their work zones (*3*). Although information regarding crash location (and possibly crash severity) will be available through these sources, other crash characteristics will not. In addition, non-crash events (stalls, debris in road, etc.) may also be captured by service patrol dispatch logs, which can reduce the quality of this measure if these events cannot be separated from the dataset.

MOBILITY (TRAFFIC OPERATIONS) PERFORMANCE MEASURES

Queuing Performance Measures

Both queues and traffic delays reflect the effect of work zones on traveler mobility, and are correlated with each other. Both the safety considerations associated with the formation of queues and the fact that they can be directly measured more easily than delays has led several agencies to establish policies as to the maximum acceptable length and duration of work zone queues. Table 3 presents several work zone queue-related performance measures for agencies to consider.

Both Ohio and Indiana (DOTs) have established policies on acceptable work zone queue length and duration as follows:

- *Queues less than 1 mile are acceptable at all times,*
- *Queues between 1 and 1.5 miles cannot exist for more than two consecutive hours, and*
- *Queues longer than 1.5 miles are not acceptable for any duration (7, 8).*

As can be seen, the measures shown in Table 3 are more detailed than simply whether or not a queue formed at a given work zone. Queue frequency, length, and duration are all important attributes to be captured in work zone queue performance measures. Generally speaking, it is preferable to have multi-level performance measures rather than simple present/not present or yes/no performance measures whenever possible (*9*).

During a milling and overlay project on I-95 in North Carolina, queues developed on only 26 percent of the days when 1 of 2 travel lanes were closed in a given direction. Conversely, nighttime lane closures for construction work on I-405 in Seattle resulted in queues forming on 81 percent of those nights when lanes were closed (2). When queues occurred at either site, the lengths and durations of the queues varied dramatically from day to day.

Frequency, length, and duration are needed to fully characterize traffic queues at work zones. All are important components in work zone queuing performance measures.

Table 3. Potential Queuing Measures

Measure	Why It is Important	Considerations in Using It
Number or % of days or work activity periods when queuing occurred	Some work zones have only occasional queues, whereas others will experience queues on almost daily basis	It is more difficult to detect and record infrequent queuing unless traffic conditions are being continuously monitored and recorded.
Average queue duration	Useful for road user cost computations	Very short-duration queues cannot always be detected. Also, crashes or other external influences can skew work zone queue duration values.
Average queue length	Useful for road user cost computations	Defining the beginning and ending points of a queue can be a challenge. Also, crashes or other external influences that occur can skew work zone queue lengths.
Maximum queue length	Maximum queue lengths can help agencies assess whether advance warning signage is placed far enough upstream of the lane closure to adequately warn approaching motorists.	Queue lengths can change rapidly over time, and may be at a maximum for only a very short period of time. Also, queue lengths may differ by lane, depending on the geometrics of the roadway and driver behavior.
% Time when work zone queue length exceeds xx mi	Combines queue frequency, length, and duration into a single performance measure	Queues due strictly to external influences (weather, crashes) should be examined separately from queues that are due strictly to work zone operations and temporary lane closures. This measure will typically require continuous monitoring of traffic conditions.
Amount (or % of ADT) that encounters a queue	The number of vehicles that encounter a queue is useful for evaluating appropriate beginning and ending times of temporary lane closure periods.	Queues can cause diversion from the work zone, the amount of which is difficult to predict.

ADT = average daily traffic (vehicles per day)
xx = threshold level as defined by the agency

Agencies will likely be interested in examining queue performance measures that are due to certain work activities (temporary lane closures, close proximity of work equipment to travel lanes) separately from those measures that include external queuing influences in the work zone. For example, adverse weather conditions can slow vehicle speeds and increase gaps between vehicles, thereby increasing the likelihood of queues developing where one typically does not occur. The occurrence of a traffic crash in the limits of a work zone may also create a queue where one normally would not occur, or significantly increase the length or duration of a queue that normally exists. While it can be argued that those types of queues are also related in some fashion to the design of the work zone, queues that occur strictly because of work operations reflect directly upon agency work zone policies and procedures in terms of how many lanes are allowed to be closed or hours when lanes can be closed.

Queuing performance measures in Table 3 are defined relative to a no-queue condition during the periods of work activity. The assumption is that any queues that develop are the direct result of the work activity and temporary lane closures required. If recurrent queues were occurring at the site before the project began, these queue performance measures would need to be defined in terms of changes from their pre-work zone levels. Likewise, if long-term lane closures were used at a project that resulted in queues only during peak periods, it may be more appropriate to evaluate queue performance measures strictly over the peak period at that site.

Delay Performance Measures

Table 4 describes several possible work zone delay performance measures for use. Delays are needed to estimate road user costs caused by work activities. Road user costs drive decisions regarding bidding approaches and contracting strategies employed, incentive and/or disincentive provisions used in the contract, techniques used to accelerate construction, and the traffic impact mitigation strategies that may be implemented. Separate delay measures are often used to describe the impacts of the work zone to an individual vehicle (delay per vehicle), and to the collective motoring public overall (total vehicle-hours of delay).

The Oregon DOT work zone policy is to limit delays due to work zone lane closures to no more than 10 percent above the peak travel times that would normally have occurred traveling through a roadway corridor (10). The limit is for the entire corridor, regardless of the number of work zone lane closures in place in the corridor at one time.

Table 4. Potential Delay Measures

Measure	Why It is Important	Considerations in Using It
Vehicle-hours of delay per: - Work period - Work period when queues are present - Peak period - Project	Multiplied by the value of user travel time, these measures define road user costs that are attributable to work zone mobility impacts, stratified by the conditions and times when they occur.	In areas already experiencing recurrent congestion, it is necessary to first determine the delays normally occurring on the roadway prior to the start of the work zone
Average delay per: - Entering vehicle - Queued vehicle - Peak period vehicle	Motorists are more sensitive to individual vehicle delays than to total delays; these measures can be stratified to better define the impacts to various vehicle subsets.	Continuous travel time and volume data are desired to compute average and maximum delay measures, as well as the percentage of vehicles which experience delays more than deemed acceptable by the agency.
Maximum per-vehicle delay	Knowing the upper bound on maximum individual delay experienced during a project can be helpful in responding to public complaints about perceived level of mobility impacts.	External influences (crashes, vehicle stalls, weather conditions) can dramatically increase work zone delays. Delays during these events should be categorized separately from those due strictly to work activities.
% Vehicles experiencing delays greater than xx minutes	In addition to knowing the magnitude of delays, knowing what percentage of drivers are experiencing more than agency-defined tolerable delays is also important for program-level reviews.	Diversion from the work zone due to delays makes continuous travel time and volume monitoring highly desirable.

xx = threshold level as defined by the agency

Both total delay (vehicle-hours) and individual vehicle delays (minutes per vehicle) are important indicators of work zone mobility performance.

Recognizing that individual delays can vary significantly over the course of a project or even hours of a particular work shift, multiple versions of these delay measures may be needed to capture both the extreme and "typical" impacts. Another measure, percent of work activity time when motorist delays are exceeding some threshold, will be useful to agencies that have identified a maximum tolerable level of motorist work zone delay.

In locations that are not experiencing recurrent congestion, any delays occurring are directly attributable to the work zone. In locations where recurrent congestion is already occurring, it will be necessary to establish baseline delays prior to the start of the work zone so that the additional impacts of the work zone can be appropriately determined.

Travel Time Reliability Performance Measures

In addition to the congestion and delays that can be created, work zones can also make travel times less predictable or reliable for motorists who regularly use a particular facility. Drivers want dependable travel times so that they can better plan their departure and arrive at a destination near a desired time (*11*).

Roadways with highly variable travel times require motorists to "buffer" in more time in their departure time decision to ensure that they are likely to arrive on time, even though there is a chance that they will arrive much earlier than necessary if travel conditions are favorable. One way to describe travel time reliability is through a buffer index performance measure, defined for a particular time period (peak, nighttime, etc.) as:

$$Buffer\ Index = \frac{95^{th} percentile\ Travel\ Time - Average\ Travel\ Time}{Average\ Travel\ Time} \qquad \text{(Equation 1)}$$

The use of the 95^{th} percentile travel time as the upper limit implies that someone who allows that amount of time for their trip would arrive late no more than once every 20 trips (or days). Similarly, use of an 80^{th} percentile travel time in the above computation would correspond to arriving late no more than once every five trips (or days).

Currently, most state DOTs do not establish separate work zone travel time reliability performance measures. However, efforts to evaluate the potential usefulness of work zone travel time reliability performance measures were positive (*2*). For those agencies that already track travel time reliability performance measures on a regular basis, examining work zone mobility-related impacts with this type of measure should be considered.

The effect of long-term lane closures on travel time reliability due to two closely-spaced projects was recently evaluated for a section of I-15 in Las Vegas, Nevada (2). Results indicate that the closures increased the peak period 95th percentile buffer index from 22 percent before the closures to 64 percent northbound during the closures. Southbound, the buffer index increased from 22 percent before the closures to 70 percent during the closures. In other words, the presence of the work zone meant that drivers had to allow an additional 40 to 50 percent of their average travel times for their trips to ensure they did not arrive late at their destination.

Some agencies may use other measure to characterize travel time reliability on their facilities, such as a planning time index or the percent of time that congestion (i.e., delays or travel times) exceeds some defined threshold level. These same measures can continue to be monitored during work zone conditions as well, and the change attributable to the work zone can be calculated.

Work zone travel time reliability performance measures should be considered in regions where travel time reliability is already being monitored.

Other Types of Work Zone Mobility Performance Measures

Although queues and travel time delays are the most direct indicators of work zone mobility impacts, some state DOTs have tried and are using other types of performance measures that relate to work zone mobility. Table 5 summarizes several of these types of measures. Average speeds in the work zone can provide an indication of the quality of service being provided. Often, multiple data collection locations are needed to fully characterize operating conditions throughout the work zone. Some agencies use level-of-service (LOS) as a mobility-related performance measure for work zones within or near at-grade intersections. Work zone volumes or throughput are another type of measure that has been used. A few agencies track the percent of time a project is operating at or near free-flow speeds as a work zone mobility performance measure. Although less objective than other mobility-related performance measures, customer complaints or surveys are also used by many agencies to assess how well mobility is being maintained in work zones.

The Missouri DOT uses a rating process during project inspections to determine the percent of work zones under its jurisdiction meeting agency expectations regarding traffic flow. Recently, the DOT has expanded the rating process to non-technical employees who drive through a work zone during their daily travels. In addition, a website survey was created to allow motorists to rate a work zone as well (*3*).

Table 5. Other Potential Mobility-Related Measures

Measure	Why It is Important	Considerations in Using It
Average speed	Speed is easy to measure, and can be obtained at multiple locations (if desired) to evaluate operating conditions in various parts of a work zone.	The location of data collection can have a significant effect on speeds obtained. If handheld devices are used, measurements must be taken from close to the actual travel lanes to reduce errors.
Intersection Level-of-Service (LOS) maintained during the project	Some agencies use impact assessment tools that provide intersection LOS, and so have based their policies and acceptable thresholds around that measure.	LOS cannot be collected directly in the field. It must be computed from volume, delay, and signal timing data.
% Work zones meeting agency expectations for traffic flow	This is a program-level measure that can be directly and quickly obtained by agency staff as part of project field reviews and inspections.	Agency personnel performing the assessments may not all have the same expectations. Also, agency expectations may not always align with motorist expectations.
Customer complaints	Complaints can help identify in real-time which work zones are creating major impacts, and allow agencies to implement corrective measures quickly. Most agencies already have procedures in place to track and respond to all complaints received from the public.	Information received in a complaint can be subjective and incomplete. Agencies can spend considerable time deciphering and then responding to each complaint received.
Customer survey ratings	Surveys about travel conditions in work zones can be done fairly quickly and can yield useful insights about problems and possible corrective actions.	Unless properly designed, survey results can be somewhat biased (positively or negatively), which can reduce their effectiveness.

SOURCES OF DATA FOR WORK ZONE PERFORMANCE MEASUREMENT

Once work zone performance measures have been selected, agencies need to define the data sources and methodologies that will be used to collect and compute those measures. For some measures, only one data source and/or methodology will exist for an agency; for others, several sources and methodologies may be available. Agencies must balance the data needs for performance measures with available resources and other factors to determine the most appropriate data source or methodology to use.

For each category of measures, agencies must consider the following:

- Data needs,
- Available data sources and data collection methodologies, and
- Computations required to transform the data into the measures desired.

EXPOSURE PERFORMANCE MEASURES

Work zone exposure performance measure data needs fall into three basic categories:

- Project characteristics,
- Work activity information, and
- Traffic volumes.

Table 6 summarizes both the data needs that may exist and the possible sources of data for each of these three categories. Typically, the extraction and documentation of most project characteristics for work zone performance measurement purposes must be done manually, since automated methods for extracting the key data elements do not currently exist within most agencies.

Depending on the agency, work activity and temporary lane closure data may be available electronically or require manual extraction and documentation. Work activities that involved staggered implementation of temporary lane closures at night (i.e., closing a single lane initially, then a second lane a short time later, a third lane still later, etc.) require additional effort to document accurately. If worker injury rates based on work activities are of interest, it will be necessary to obtain counts of workers present during each activity period. These data can be very time-consuming to obtain.

Historical or planning-level traffic volumes are normally limited to AADT estimates. If a finer level of detail is needed, the agency must use time-of-day distributions from nearby count station data to estimate hourly traffic volumes during the work zone. If mobility impacts are significant, such estimates may overstate the amount of traffic volumes passing through the work zone because of driver diversion to alternative routes and changes to departure times, destinations, or travel modes.

Table 6. Work Zone Exposure Performance Measure Data Needs and Sources

Data Needs	Sources of Data
Project Characteristics	
• Length • Basic project phasing • Major roadway capacity constraint locations, e.g., - Long-term lane and shoulder closures - Lane shifts - Detours - Narrowed lanes - Sections with portable concrete barrier located close to travel lanes - Construction vehicle access points	• Project plans (especially traffic control plans) • Agency construction management database
Work Activities	
• Dates and times of work activities • Data about each short-duration, short-term or intermediate-term lane closure: - Dates - Installation and removal times - Location - Number of lanes closed and left open - Length • Number of workers present during work activity hours	• Daily project inspector diaries • Traffic control subcontractor daily activity logs • Lane closure request/management databases • Agency construction management databases[1] • Contractor payroll records
Traffic Volumes	
• Annual Average Daily Traffic (AADT) counted or estimated for the facility • Traffic count samples during time periods of interest • Continuous hourly traffic volumes by direction • Vehicle classifications (especially the percent of large trucks in the traffic stream)	• Historical automatic traffic recorder (ATR) counts from nearby count stations • Agency planning and project development AADT estimates • Periodic volume sampling before and during the project via manual counts or temporary traffic counters • Real-time volumes from existing TMC traffic sensors • Real-time volumes from portable work zone ITS traffic sensors

ITS = intelligent transportation system TMC=transportation management center

[1] Some agencies use construction management software (such as Trns•port SiteManager) to electronically record their daily diary entries on projects. Although currently not included as part of the capabilities of those systems, future enhancements could be made to these systems to allow users to easily extract, summarize, and report work zone exposure information (times of work activity, temporary lane closure statistics, etc.)

SAFETY PERFORMANCE MEASURES

Safety performance measure data needs depend on the particular measures that an agency has selected. In turn, the data source(s) available to an agency will influence which performance measures are of greatest value to the agency. Categories of data needs include:

- Traffic crashes,
- Worker accidents and injuries,
- Agency work zone inspection scores, and
- Service patrol or emergency medical service dispatches to the project.

Table 7 provides a summary of specific data needs and sources for each of these categories. For most agencies, traffic crash data serves as the primary source of work zone safety performance measure data. Crash data timeliness can be a significant issue for some agencies. Whereas significant time lags can be tolerated for post-project and bi-annual reviews of agency policies and procedures, use of crash data for safety performance measurement on current projects is significantly hindered. Some agencies have moved towards electronic crash record entry by investigating officers, which has significantly reduced lag times in obtaining crash data from a project location. Another option available is to establish relationships with the local law enforcement agency for key projects, and periodically (e.g., every two weeks) request copies of the actual crash reports prepared by officers within the project limits. This approach requires a time commitment by the highway agency to obtain the crash reports and manually enter the desired crash information into a database for analysis.

> Ohio DOT 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. A team trained to identify underlying causes to crashes investigates major crash “hotspots” identified through the monitoring process so that the agency can make improvements to the work zone (*3*).

Agencies will have access to worker accident and injury data maintained by its own occupational safety division. However, since the majority of roadwork is performed by private-sector contractors, additional data sources will likely be needed in order to fully assess highway worker safety performance. The BLS database can provide general data on construction industry injuries and fatalities in a given state. Meanwhile, some agencies participate in the National Institute of Occupational Safety and Health (NIOSH)

Fatality Assessment and Control Evaluation (FACE) program (*12*). Highway worker fatality reports occurring in participating states can be reviewed for insights into the causes and contributing factors to the accident. If more comprehensive data are desired, an agency may also choose to establish a formal reporting process for injuries, similar to the program that the New York State DOT has established (*3*). Some agencies may be able to obtain highway contractor injury records, but concerns about worker privacy must first be addressed.

Table 7. Work Zone Safety Performance Measure Data Needs and Sources

Data Needs	Sources of Data
Traffic Crashes	
• Time, location, and direction of travel • Severity • Manner of collision • Contributing factors	• Statewide crash database • Manually-collected crash reports from the local police agency
Worker Accidents and Injuries	
• Time, location, and activity • Type (i.e., injuries involving traffic) • Severity	• Agency occupational safety division records • Agency-established injury reporting system • U.S. Department of Labor Bureau of Labor Statistics (BLS) • National Institute of Occupational Safety and Health (NIOSH) Fatality Assessment and Control Evaluations (FACE) • Highway contractor injury records
Agency Work Zone Inspection Scores	
• Rating scores	• Agency work zone inspections or field reviews
Service Patrol/Emergency Medical Service (EMS) Dispatch to Project Location	
• Time and location of dispatches • Type of response (for service patrol dispatches)	• Agency service patrol dispatch logs • EMS dispatch logs

Agency work zone inspection scores can be a simple but effective data source for work zone safety performance measurement. Evaluation of the quality of many different features of each work zone (sign condition and placement, pavement marking quality, channelizing devices, barriers, etc.) can be used as a surrogate of agency efforts to ensure safe work zones. The use of multi-dimensional criteria to rate each of these features (i.e., a 1 to 5 scale) can provide much more useful information to agencies than simple pass/fail ratings of each work zone (*9*). Such scores can be summed or averaged in different ways and tracked over time to see if agency efforts to improve work zones are being successful.

Another method to circumvent time lags in obtaining crash data from project locations is to use service patrol or emergency medical service dispatch logs. For service patrol dispatch data, information about each dispatch is needed in order to remove actions unrelated to the safety of the work zone. Examples of these include vehicle stalls or other motorist assistance activities, and the removal of non-construction debris in the roadway.

MOBILITY (TRAFFIC OPERATIONS) PERFORMANCE MEASURES

Data needs for work zone mobility performance measures also depend on the measures of interest to the agency. Likewise, data sources available to the agency can influence which measures the agency uses. For most agencies, available data sources will vary from project to project, and the choice of data source(s) will be fairly obvious.

Categories of data needs include:

- Traffic queues,
- Travel times and delays,
- Agency ratings of traffic mobility impacts, and
- Customer complaints/customer ratings.

Table 8 provides a summary of the data needs and available sources of data for work zone mobility performance measurement.

Manual documentation of **traffic queues** allows mobility performance measurement to occur at work zones where no other sources of mobility data are available. Project field staff could be called upon to provide this data, or other potential data sources could be used as listed in the table. If this data source is selected, it is important that upper agency management supports and emphasizes the importance of gathering the data to ensure that it is consistently done.

> The Pennsylvania DOT has attempted to use law enforcement personnel to collect queue length data while providing overtime-duty enforcement services at the work zone. The amount and quality of queue data collected by enforcement personnel to date has varied dramatically from project to project, making it difficult for the agency to rely on this data source (*3*).

Table 8. Work Zone Mobility (Traffic Operations) Performance Measure Data Needs and Sources

Data Needs	Sources of Data
Traffic Queues	
• Beginning and ending time • Location • Direction of travel • Location relative to work space and/or lane closure merging taper	• Manual on-site observations by field personnel • Visual observation via closed-circuit television operated by TMC staff • Periodic drive-through inspections by staff dedicated to work zone traffic operations monitoring • Existing TMC spot speed traffic sensors • Portable work zone ITS spot speed traffic sensors (or other portable traffic monitoring devices) deployed for the project
Travel Times/Delays	
• Time • Location of delays • Direction of travel • Historical travel times	• Existing TMC spot speed traffic sensors • Portable work zone ITS spot speed traffic sensors (or other portable traffic monitoring devices) deployed for the project • Point-to-point travel time measurement systems (automatic vehicle location, automatic vehicle identification, license-plate recognition and tracking, Bluetooth tracking, cellular telephone signal tracking) • 3rd party speed and travel time data • Periodic drive-through inspections by staff dedicated to work zone traffic operations monitoring
Agency Ratings of Work Zone Mobility Impacts	
• Rating scores	• Agency work zone inspections or field reviews of mobility impacts
Customer Complaints/Ratings	
• Complaints • Survey results	• Agency complaint files • Survey response database

ITS= intelligent transportation system
TMC=transportation management center

This data source is best suited to locations that normally have no congestion and queuing present during the times when work zone impacts are of interest (e.g., during temporary lane closures). In this way, the queues that are documented at the project site can be attributed solely to the presence of the work zone. If queues and traffic congestion are normally present when work zone queue measurements are desired, some amount of "before" data will be required to factor out the pre-work zone impacts from what is observed during the work zone itself.

A simple form that can be used for documenting queue lengths by field personnel is provided in the appendix of this primer. It is recommended that multiple queue length estimates be recorded, and that the duration of the queue also be documented (a queue may exist for only a portion of a work period). The more detail gathered during each work zone activity that creates a traffic queue, the more accurate the agency can calculate estimates of the mobility impacts of the work zone.

Table 8 also indicates that a number of possible sources exist for obtaining **travel time and delay** data. Both existing transportation management center (TMC) systems and portable work zone intelligent transportation system (ITS) deployments can provide useful data from spot speed traffic sensors that are positioned along the roadway. Speeds can be extrapolated between sensors and linked together to estimate overall travel times along the roadway segment. The quality of these estimates depends on the spacing between sensors and whether the sensors are properly maintained and calibrated.

The use of portable work zone ITS continues to gain acceptance with state DOTs and other highway agencies nationally. Although few agencies will likely deploy such systems strictly for performance measurement purposes, they can be a useful source of mobility performance data. Several systems are available commercially, and many have been tested and validated in field trials (*see the FHWA website at http://ops.fhwa.dot.gov/wz/its/index.htm for more information regarding these tests*). The ability of agencies to deploy portable systems is further being enhanced through the development of portable traffic monitoring devices (PMTDs).

One type of portable traffic monitoring device (PMTD) has been developed to fit within a standard temporary traffic control channelizing drum. The device consists of a power supply, wireless communication capabilities, radar, and a global positioning system (GPS) antenna. The vendors of the device gather the data (primarily speed), process it, and post it to an internet site for access by the highway agency personnel or whoever else has been authorized for access. The processed data can also be sent back out into the field to disseminate current travel times on portable changeable message signs or displayed on a public website. Tests of the technology through the national evaluation of the SafeTrip-21 initiative were favorable (13).

If use of a permanent TMC system is anticipated for measuring mobility performance at a particular work zone, it is important to verify beforehand that work zone activities will not temporarily disable the sensors. A disruption in data can occur because of any of the following:

- Temporary loss of power to the sensors,
- Inadvertent movement or removal of a sensor by the work crew,
- Parking of construction vehicles on or near a sensor, and/or
- Damage to the sensor (primarily a problem for inductive loop sensors imbedded in the pavement).

During a recent test of permanent TMC system data usage for work zone mobility performance measurement, many of the inductive loop sensors that could have been used for work zone traffic data were found to be inoperable on nights of work activity. It was theorized that temporary power disruptions were required for the work activities, which rendered the spot speed sensors inoperable and made it impossible to measure traffic impacts on those nights (3).

Regardless of whether a permanent TMC system or a portable work zone ITS deployment is going to be relied upon for work zone mobility performance data, several "tips" are provided below to maximize the probability that quality data will be available.

Tips for Using Spot Speed Traffic Sensor Data for Work Zone Mobility Performance Measures:

- ✓ ***Ensure that sensors will exist within the work zone and upstream for a distance greater than the anticipated length of congestion and queues that may develop.***
- ✓ ***Deploy sensors as closely spaced as is practical and affordable, to increase travel time and delay measurement accuracy.***
- ✓ ***Ensure that traffic sensor spot speed data will be archived for use in work zone performance measure computations.***

Point-to-point travel time data can also be used to obtain speed and travel time data in advance of, and through, a work zone. Available technologies for collecting point-to-point travel times include:

- Automatic vehicle location (AVL),
- Automatic vehicle identification (AVI),
- License-plate recognition,

- Bluetooth tracking, and
- Cellular telephone signal tracking.

AVL systems track (continuously or intermittently) an instrumented vehicles as it traverses a route. Fleet vehicles (buses, delivery companies, emergency vehicles, etc.) are common users of this type of technology. These systems can provide instantaneous speeds at specific locations as well as elapsed travel times over a given roadway segment. The quality of the data available depends on the frequency of vehicle position and speed updates. Typically, very few vehicles in a traffic stream will be outfitted with this type of technology, which may limit its usefulness for work zone mobility performance measurement. It is likely that most agencies will not have direct access to this type of data unless they use such a system for their own vehicles.

The FHWA Office of Freight Management is examining the use of transponder data from large trucks for monitoring traffic conditions on various roadways. The usefulness of this dataset for work zone mobility performance measurement was inconclusive at most pilot test locations due to the low sample sizes available. At one urban freeway location where long-term lane closures were in place and peak-period travel conditions were significantly impacted, the transponder data were reasonably consistent with the other available data sources at that site (2).

AVI systems rely on antennae mounted at specific locations that can detect a uniquely-numbered sensor in a vehicle at each antennae location and compute elapsed travel times between antennae locations. Electronic toll tags are the most common type of AVI system in use for this purpose. Consequently, work zones on or near toll facilities may have ready access to this data for traffic monitoring and performance measurement purposes.

Electronic license-plate recognition systems with plate number matching software function very similarly to AVI systems, and have also been shown to effectively track travel times through a work zone (*14*). More recently, research on the ability to monitor and track electronic devices enabled with “Bluetooth” technology in vehicles traversing a segment of roadway has also shown promise for monitoring work zone travel times between two readers installed on the roadside (*15*). Tests indicate that its effectiveness is dependent upon the level of market penetration of Bluetooth-enabled devices in the vehicles and traffic volume levels on the roadway segment. Operating in a slightly different format, technology also exists to track the global-positioning-signal (GPS) of navigation devices, and to track cellular telephone signals (via triangulation methods from multiple cellular telephone transmission towers in the area) as they traverse through a network (*16*).

In some locations nationally, travel time data is being made available to agencies for purchase from private-sector providers. These providers “fuse” data from a range of systems and technologies like those described above to create a product that has market value. Several agencies are considering the purchase of this type of data on roadways where they currently do not have traffic surveillance. When work zones occur on these roadways, the third-party data can be used to assess work zone performance. Research continues to evaluate the quality of data that such providers can deliver.

Although point-to-point travel time data does have some advantages for agencies, there are also important caveats to consider if this type of data is to be used for work zone mobility performance measurement. First and foremost, it is important to recognize that this type of technology does not provide traffic volume data. Thus, it will be necessary to supplement these data with traffic count data, or make assumptions regarding the amount of traffic passing through the work zone over time. For AVI, license-plate recognition, and bluetooth systems, the distance between readers is also an important consideration in measuring work zone impacts. Longer distances between antennae also limit how well such systems can detect the physical extent of congestion. Short distances of congestion caused by a work zone can be “masked” somewhat when vehicles travel a significant portion of distance between antennae at near free-flow speeds.[2]

In contrast to the various technologies available to electronically measure point-to-point travel times through a work zone, many agencies obtain samples of travel times and delays through their work zones during routine project inspections or through student interns or other staff who are dedicated to travel time data collection efforts. To be most useful, such measurements should be made during time periods when the impacts are anticipated to be the most significant, such as during peak hours or during times when lanes are temporarily closed.

Agency ratings of traffic conditions, customer complaints, and customer survey ratings have all been discussed previously in terms of their value for work zone safety performance measurement. Depending on agency resources, these data sources can be useful in mobility performance measurement as well. Consideration needs to be given to potential biases that may exist in these data (agency staff may rate traffic conditions higher than drivers might, for example). Even so, these data can be

[2] Depending on the spacing between AVI antennae on the roadway segment of interest, it may be desirable to temporarily install portable AVI readers at strategic locations near the work zone (at the beginning of the lane closure, at the end of the work zone, at the location of the maximum length of queue expected, etc.) to precisely tailor the travel time data to the work zone region of interest.

extremely useful to agencies for both project-level evaluations and program-level assessments of agency policies and procedures pertaining to work zone mobility.

So, which data source is the best for work zone mobility performance measurement? The answer to that question depends on the agency and the projects to be measured. All sources have their advantages and disadvantages. Table 9 provides an overall comparison to aid in the decision-making process.

Table 9. Comparison of Various Work Zone Mobility Data Sources

Data Source	Advantages	Disadvantages	Other Considerations
Manual Measurement of Queues:			
By Field personnel	• Easy to implement • Minimal additional cost	• Increases work load of field personnel • Not as useful at locations with pre-work zone congestion	• Important to note location of start and end of queue relative to work zone lane closure each work period
By visual observation on CCTV by TMC staff	• Easy to implement • Minimal additional cost	• TMC staff can be called away to manage incidents or other transportation issues in the region	• Staff may need to document queue extent by visible landmarks for later determination of lengths
Electronic Spot Speed Data:			
From existing TMC already in place	• Minimal additional cost • "Before" data is available to do before-during comparisons	• Location of devices may not be optimum for work zone assessment purposes	• Important to ensure that sensors will remain operational during work activities
From work zone ITS devices	• Can control where devices are placed • Minimal additional cost if system installed to provide real-time travel time information or other purposes	• Work zone ITS is sometimes costly to include in a project	• Important to make sure that sensors will extend beyond the limits of anticipated congestion
From portable traffic monitoring devices	• Relatively inexpensive • Easy to deploy and retrieve • Can be easily moved as needed	• Devices may have to be recharged regularly	• Important to make sure that sensors will extend beyond the limits of anticipated congestion
From truck transponder data	• Does not require agency to purchase technology to deploy • Does not require technology to be moved or maintained	• Sample size can be an issue for truck transponder data • May require purchasing from third-party vendors	• Important to remember that the spot speeds will be distributed across the segment length for which they are requested

Data Source	Advantages	Disadvantages	Other Considerations
Electronic Point-to-Point Travel Time Data:			
From AVL systems	• Very accurate tracking of speed profiles possible • Potential exists for determining beginning and ending points of queues	• Vehicle fleets to draw data from are limited	• Will require agreements with agencies or vendors who collect these data
From AVI toll tags	• Available sample size can be fairly high • Easily implemented on toll facilities	• Deployment of additional transponder readers will increase costs	• Most useful in regions where a significant portion of the driving population has toll tags • May require agreement with toll agency to gather data
From license plate recognition systems	• Available sample size can be fairly high	• Costly to implement	• May create concerns about privacy with local citizens
From bluetooth readers	• Data can be obtained unobtrusively from roadside devices	• Detection range can vary depending on site conditions	• Dependent on the volume of traffic present and market penetration of bluetooth devices
From cell phone tracking	• Large potential sample size within traffic stream	• Requires agreements with third-party vendors to obtain data	• Dependent on the volume of traffic present
Other:			
Customer surveys	• Perceptions about performance can be obtained • Can evaluate across a broad range of user groups	• Can be costly to perform, especially to obtain demographically-balanced data	• Surveys generally have a low (< 30 percent) response rate, which increases the sample size needed for useful results
Citizen complaints	• Problems are identified very fast	• Only negative input is received	• Typically requires documentation of how complaint was resolved
Ratings or scoring by agency staff	• Agency can adjust data elements and amount of data collected as needed • Can be incorporated into existing inspections at many agencies	• Agency assessments of its own activities may not match public perceptions	• Correlations between ratings and other measures (i.e., safety) have not been well established

ESTIMATING WORK ZONE DELAY AND QUEUE LENGTH PERFORMANCE MEASURES

Although queues and delays both characterize the same congested conditions at a particular work zone, they do represent different measures of congestion. Each type of measure can either be obtained directly from the data, or estimated using extrapolation procedures or fundamental relationships of traffic flow. For example, elapsed point-to-point travel times can directly measure delays, whereas field personnel can directly observe and record when and where the queue starts and ends. Conversely, spot speed sensors from a work zone ITS or from a functioning TMC can be extrapolated over segments of roadway to estimate travel times through a work zone.

In some jurisdictions, both types of data may be used to measure work zone mobility performance. While the use of different measures is not necessarily a problem for project-level evaluation, it can create a challenge for agencies wanting to use a single type of measure (or both measures) for program-level assessments. If this is the case, agencies will need to estimate the other types of performance measures from the data they have collected. Fortunately, this is fairly easy to accomplish, and steps to do so are covered in this section of the primer.

Two types of computations are described:

- Estimating travel time delays from manually-recorded queue length data, and
- Estimating travel time delays and queues from a series of spot sensors.

In addition, discussion is provided regarding the possible use of traffic simulation tools for estimating performance measures that are not monitored directly.

ESTIMATING DELAY FROM QUEUE LENGTH DATA

When queues form at a work zone, traffic speeds are significantly lower through the queue than upstream or downstream of the queue. The difference between the normal speeds on the facility and the reduced speed through the queue creates the delay that a motorist joining the queue experiences.

The process for estimating delay from manually-recorded queue length data is only appropriate for work zones in locations where recurrent congestion does not occur before a work zone is implemented so that assumptions can be made as to the speeds that would have existed prior to the installation of the work zone. Given these requirements, a simple three-step computation is all that is required to estimate delay from each queue length measurement recorded:

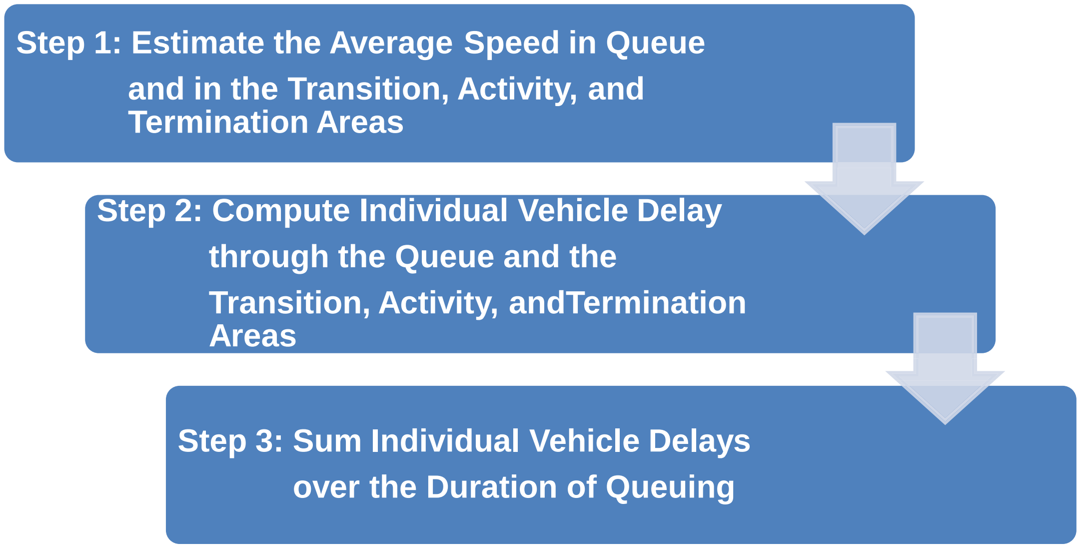

Figure 1. Steps to Estimate Travel Time Delays from Queue Length Data.

1 Estimate the Average Speed in Queue and in the Transition/Activity/Termination Areas

Queues result in travel time delays by creating slower speeds in both the queue and the transition/activity/termination areas of the work zone. If a queue has formed upstream of the lane closure bottleneck, it is first assumed that the flow rate through the work zone is at or near capacity. Given this assumption, speeds over the length of queue (L_q) are at the average speed in queue (U_q), and speeds over the length of the transition/activity/termination areas of the work zone (L_{wz}) are at the speed of capacity flow as illustrated below:

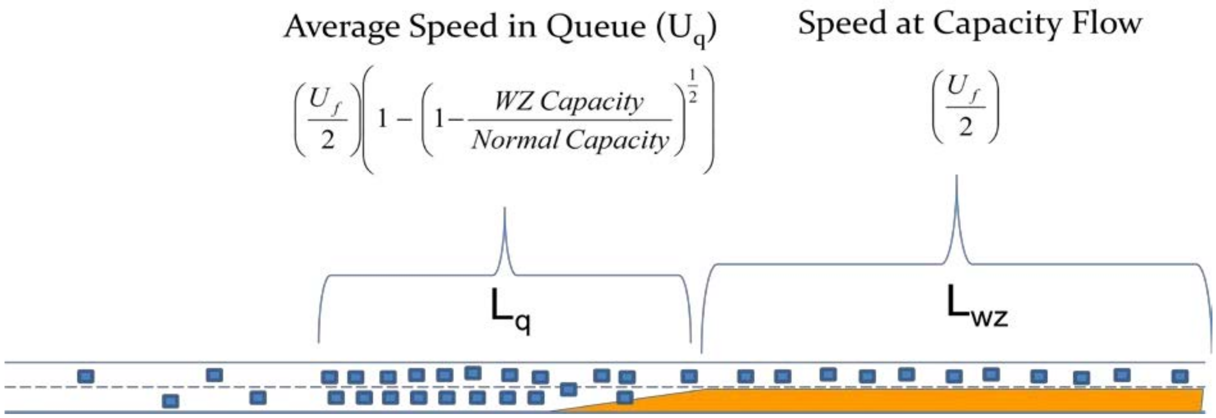

Figure 2. Components of Work Zone Delay.

Assuming a linear speed-density relationship, the speed at capacity flow through the transition/activity/termination areas can be computed simply as one-half of the free-flow speed (U_f) on the facility. Upstream of the work zone, the queue that develops will be flowing at a speed less than the capacity flow speed. Again using a linear speed-density relationship, the equation shown above produces an estimate of the average speed in queue as a function of the normal roadway capacity and the capacity through the work zone (WZ Capacity) (*17*). The capacity of the work zone can be estimated using procedures in the *Highway Capacity Manual* (HCM) (*18*). The HCM also provides procedures to estimate the normal capacity of the roadway segment. Typically, the following approximations will suffice:

- For 65- and 70-mph roadways: 2200 vehicles per hour per lane * number of lanes on the facility
- For 60-mph roadways: 2000 vehicles per hour per lane * number of lanes on the facility.

2 Compute Individual Vehicle Delay through the Queue and through the transition/activity/termination Areas

Assuming that the speeds computed in step 1 are maintained through the entire length of queue and work zone documented on the forms, estimates of average delays per vehicle through the queue and work zone can be computed. Travel at some threshold speed (most likely the desired speed or the posted work zone speed limit [U_{WZSL}]) is used as the basis against which the longer travel times would be compared:

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

If the activity area of the work zone is fairly long, congestion may not develop at the lane closure bottleneck as assumed above but at the location of the work zone activity due to driver rubbernecking or other factors. While speeds may slow significantly because of the increased distraction and lead to congested travel conditions within the work zone, speeds in that congestion will be operating closer to the speed at capacity flow than they will be to the estimated average speed in queue. Consequently, it is important to apply the correct speed estimate (speed at capacity flow, speed in queue) to the correct amount of the length of queue.

During a pilot test of work zone performance measures in Seattle, a lack of queue location documentation hampered efforts to accurately estimate motorist delays from queue length data. Estimated delays due to a 4-mile queue varied between 5.9 minutes if the queue were located entirely within the work zone lane closure, to 21.9 minutes if the queue were located entirely upstream of the work zone lane closure. At the Philadelphia pilot test site, the estimated delay for a 2.9-mile queue varied between 2.9 minutes and 29.8 minutes, depending on whether the queue was assumed to exist within or upstream of the work zone lane closure (2).

Calculation of motorist delay from queue length data requires documentation of the amount of the queue located within the work zone and the amount that exists upstream of the work zone lane closure.

3 Sum Individual Vehicle Delays over the Duration of Queuing

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 hourly volume by the average of the computed delay values at the beginning and ending of each hour. 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.

Typically, the manual documentation of queues at a work zone implies a lack of other traffic data collection devices available at the project, including hourly traffic volume data obtained while the work zone is in place. As a result, it may be necessary to rely on historical traffic volumes for these computations. If only AADT volumes are available, they will need to be distributed over the hours of the day to arrive at estimated hourly volumes.

The use of historical volumes for these (or any other volume-based) computations implies an assumption that 1) all traffic that normally used the facility before the work zone began continued to do so once the work zone was in place, or) any motorist who diverted experienced delays by using an alternative route that was equal to the delays being experienced by motorists remaining on the roadway and passing through the queue and the work zone.

ESTIMATING QUEUES AND DELAYS FROM SPOT SENSOR DATA

To estimate the queue length that exists at a work zone when spot speed traffic sensor data is used to monitor work zone mobility performance, it is necessary to evaluate traffic speeds over time and compare those speed patterns between adjacent sensors. In essence, the goal is to identify the discontinuity in traffic flow conditions between two adjacent sensors. The assumption made is that the beginning of the queue exists somewhere between those two sensor locations.

The process to estimate queue lengths and durations as well as travel time delays from spot sensor data consists of five basic steps:

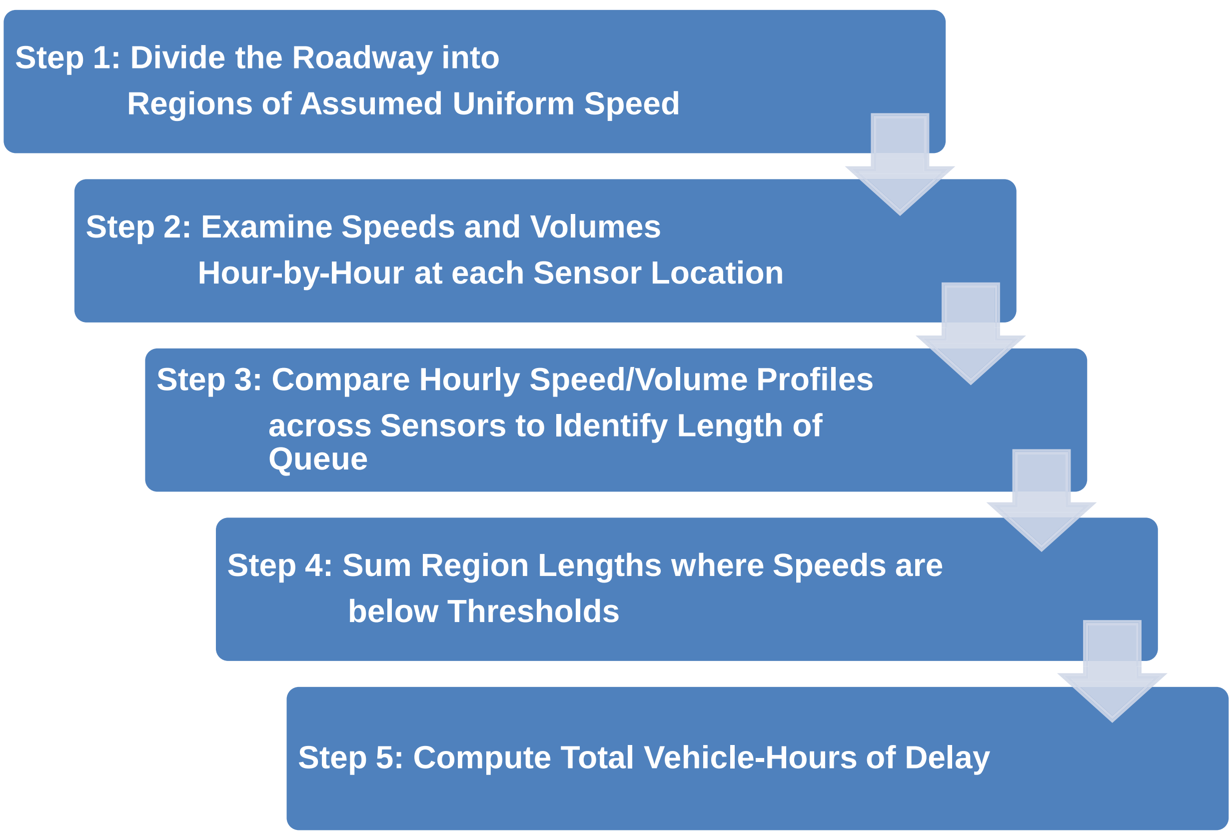

Figure 3. Steps to Estimate Queue Length and Delays from Spot Speed Sensor Data.

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.

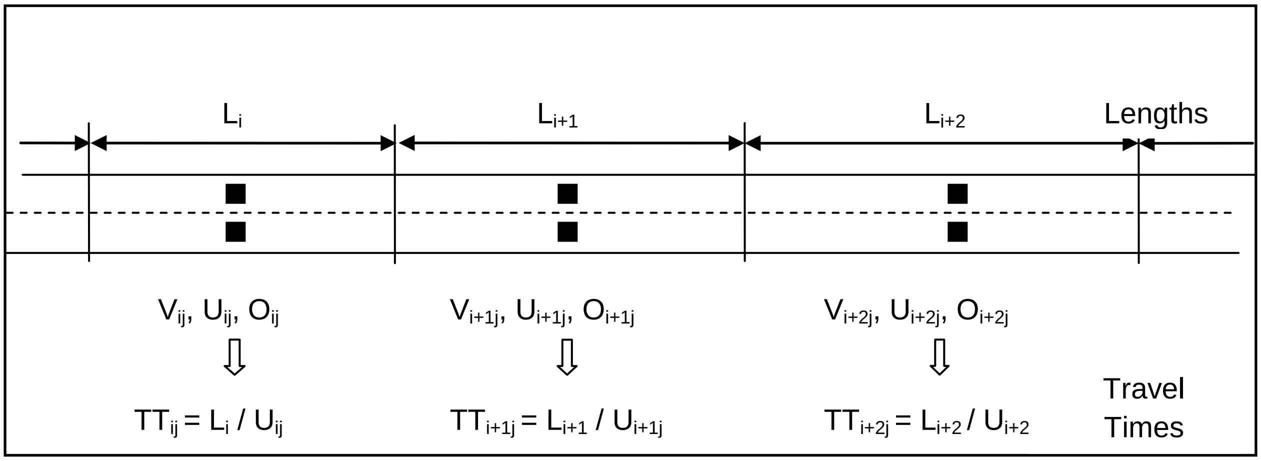

Illustration of Traffic Surveillance Estimates using Spot Sensor Data

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.

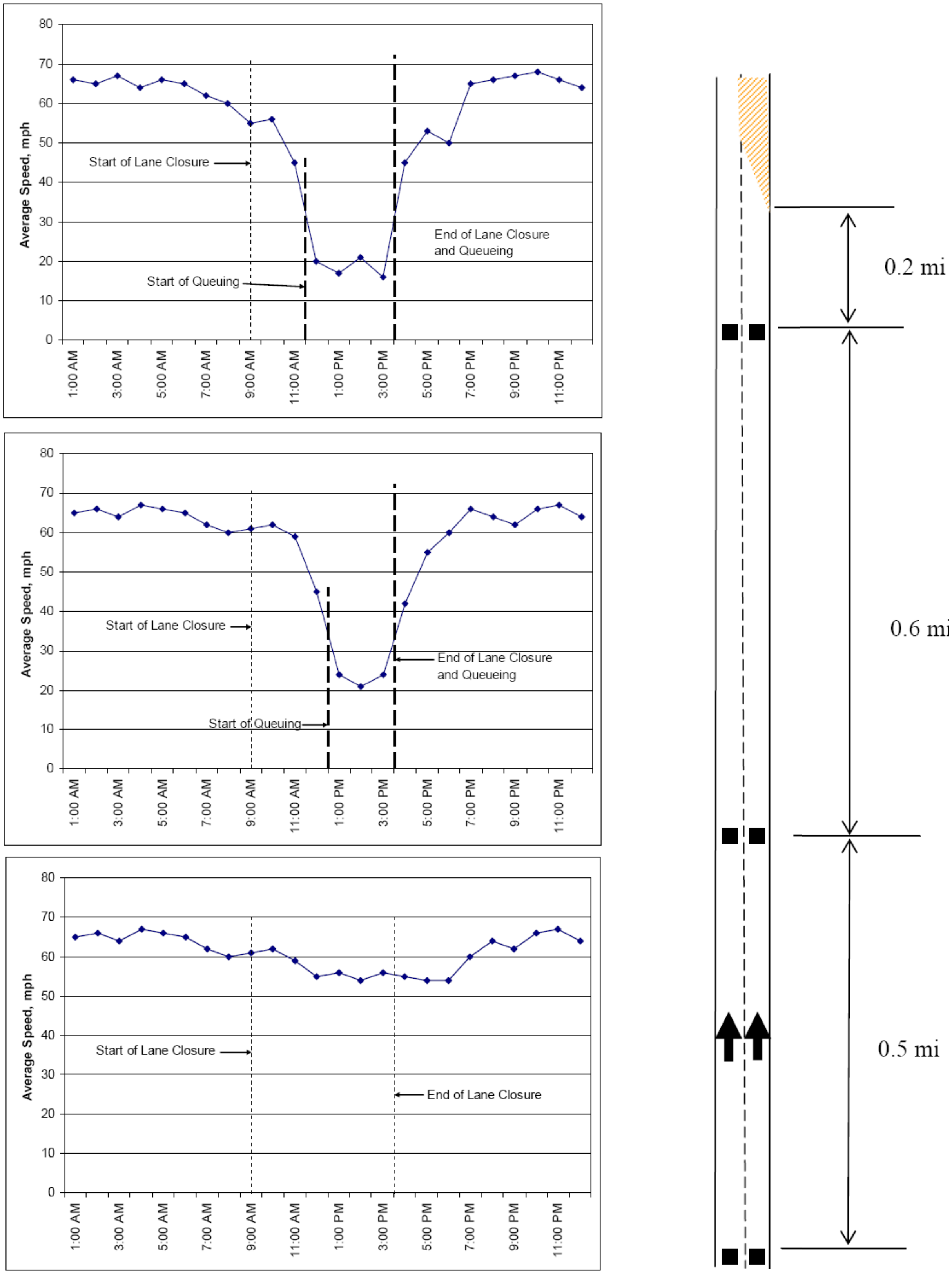

Figure 4. Example of Sensor Speed Analysis to Determine Duration and Length of Queue.

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. 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. 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

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 did drop below 40 mph at that location during the hours of work activity. The estimated queue length each hour would therefore be as follows:

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

4 Sum Travel Times across Sensors to Compute Individual Motorist Delay

As noted previously, the travel time at any point in time across a segment of roadway (TT) is simply the length of that region (L) divided by the speed at that point in time (U). Summing the individual travel times for each region together provides a total travel time over the length of roadway of interest at that point in time.

The accuracy of both delay computations and queue length estimates using traffic sensor data are very dependent upon the distance between successive sensors. Estimation errors increase directly as the length between sensor increases.

To estimate the work zone delay to an individual motorist approaching the work zone during a given hour, the travel times estimated in a pre-work zone condition are subtracted from those estimated from the speeds measured during the work zone over the same summed length of interest. As an alternative, a desired speed through the work zone can be defined and travel times based on that desired speed used to compare against actual work zone travel times. Such an approach might be used if the agency has posted a reduced speed limit through the work zone, and does not want delays measured against the normal, non-work zone speed limit and operating speeds.

5 Compute Total Vehicle-Hours of Delay

The final step in the process is to sum the individual motorist delays occurring each hour that queuing and congestion has developed. This is the average individual motorist delay each hour as computed in step 4, multiplied by the number of vehicles measured as traversing those regions during each hour, summed and converted to total vehicle-hours of delay.

USING A TRAFFIC SIMULATION MODEL TO ESTIMATE WORK ZONE PERFORMANCE MEASURES

Conceptually, it is also possible to use a traffic simulation model to estimate work zone performance measures not recorded directly through data collection efforts. Such an approach may be desirable, for example, if the agency had already developed a model for assessing potential impacts during work zone planning and design. An agency could gain valuable insights into the effectiveness of their design modeling efforts by revisiting the assumptions and data used and seeing how the resulting analysis compared to what occurred in the field.

A simulation model can also be used to estimate work zone performance measures that are not directly monitored in the field. To accomplish this, the model would first be calibrated to the pre-work zone conditions at a location. Then, the work zone would be added to the model, and the outputs calibrated to the conditions that were measured at the site. For example, if queue length and duration were measured through manual data collection methods, the model inputs and parameters would be adjusted systematically to match the documented queue patterns at the site. These adjustments may mean reducing or increasing the traffic volumes approaching the work zone or entering and exiting at various ramps upstream or within the work zone; adjusting the capacity values used for the normal roadway and for the work zone; or adjusting the geometric inputs to the model to modify the resulting capacity flows achieved through the simulated roadway section and the work zone. Once the queue patterns have been sufficiently replicated in the model, the output would provide the individual vehicle delays and total vehicle-hours of delay.

If this approach is used, it is important to correctly interpret and understand what the output from the model actually represents. For example, it may be necessary to significantly reduce the historical traffic volumes approaching the work zone in order to achieve the queue lengths observed in the field. This would imply that a significant amount of traffic diversion had occurred to other routes or travel modes. The estimates of individual motorist delay through the work zone could be fairly realistic, as they represent the delays incurred by a specific vehicle traversing a realistic length of queue and the work zone. However, if the simulation model did not include the alternative routes, the portion of traffic demand removed from the work zone would cause the vehicle-hours of delay to be underestimated by the amount of that removed traffic. Unless the agency is convinced that the diverted traffic experienced no additional travel time to their ultimate destinations, some means of accounting for diverted traffic delays would be necessary. Agencies would also need to assess how realistic the estimated diversion amounts are for the work zone of interest. If the calculated diverted traffic amounts are considered to be excessive for the roadway corridor, it would be necessary to further adjust some of the other parameters (work zone capacity, driver behavior parameters) to calibrate the model and extract the output results of interest.

WORK ZONE PERFORMANCE MEASUREMENT: MAKING IT HAPPEN IN YOUR AGENCY

Performance measurement can significantly improve work zone safety and operations. However, measurement does not just "happen." Effective work zone performance measurement occurs when an agency plans for it and incorporates it into its overall organizational processes. As stated earlier, such processes should be based on an agency's understanding of:

- What is being measured,
- How it is being measured, and
- Why it is being measured.

Several good sources of information exist that are relevant to how to set up a work zone performance measurement program (*9, 19, 20, 21*). The following is a compilation of key steps that will facilitate agency efforts to implement work zone performance measurement.

Identify and Engage Stakeholders and Other Work Zone Performance Measure Users

Agencies should begin their efforts to implement work zone performance measurement by determining those who can use and benefit from having good measures. This may include representatives from several divisions and offices within the agency as well as stakeholders outside of the agency. This group should be brought together to discuss and define the following:

- Needs for work zone performance measures,
- Work zone performance goals or targets (based on policy and procedures), and
- "Champions" for performance measurement.

This group helps to establish the "why" for work zone performance measurement. The group may also help to define how the measures will be used once they are available, such as to update requirements for monitoring in transportation management plans (TMPs) or in project plans, specifications, and estimates (PS&Es).

Pick Work Zone Performance Measures

This step answers the "what" for work zone performance measurement. The information provided in this primer identifies several types of measures that can be used. Typically, it is more useful to select a limited number of key measures to track, rather than to try to follow a large number of measures that are related to each other. A target should be associated with each measure so that everyone knows what equates to success.

Identify Data Sources

This step is critical to the success of work zone performance measurement implementation. An agency may identify a very good performance measure, but not be able to obtain the data needed to compute and track it. It may be necessary to iterate between this step and the previous one to determine what measures will meet the needs of the agency and have the data necessary to compute them. Information provided in this primer can help an agency in determining what data it has available or can easily obtain to support work zone performance measurement. Whenever available, agencies should make use of existing data sources, such as real-time traffic sensor data from regional transportation management centers and already-established third-party agreements for travel time data, for its work zone performance measurement efforts.

Define Analysis Requirements

In this step, an agency determines specifically how the data obtained will be translated to the desired work zone performance measures. Answers to questions such as the number of projects to monitor, the process to be used for selecting projects, the monitoring frequency of those projects, and the sample sizes of data to be obtained are resolved at this point.

Assign Roles and Responsibilities

At this point, an agency should determine who will have responsibility for doing the data collection, analysis, and documentation of the performance measures. Typically, this step will have budgetary implications, since staff time and other resources will be needed. Determining where the funding will come from to support this effort is important at this stage, and is why it is important to determine who the champions for work zone performance measurement are within the agency and among the other stakeholders.

Define Methods for Disseminating the Results

This step is sometimes overlooked, but is very critical to the successful implementation of work zone performance measurement. Given that an agency has already determined the needs for performance measures, decisions are made at this step as to the best methods for getting those measures to those who need the information. In some cases, it may be desirable to make the measures available to the public or to other external users. In these instances, the use of “dashboard”-type displays of key measures on an agency's website may be appropriate (*22*). In other cases, the agency may incorporate the results into its annual report. In still other cases, regular updates of the measures may be provided via email or through official memoranda to key users within and outside of the organization.

Review and Refine Measures as Needed

This process should not be considered a "one-and-done" activity. Rather, it is an iterative process that continually improves work zone performance measurement. Changes in performance measurement needs, data sources, and improved knowledge and understanding of how to use the measures to improve agency operations will undoubtedly occur over time. An agency can take an incremental approach to work zone performance measurement, selecting a few key measures to target initially, and then revising or adding to those measures as understanding of them and of their value to the agency increases. Agencies should plan to revisit their work zone performance measurement program on a regular basis. One opportunity for regular review is during a work zone process review, which is required every two years by 23 CFR 630 Subpart J (1).

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APPENDIX: DATA COLLECTION FORM FOR MANUAL DOCUMENTATION OF QUEUE LENGTHS AND DURATION

Project: ____

Date	**Times of Work Activity**				**Times of Work Activity with Lane Closures**					**Queuing During Work Activity with Lane Closures**							
	Time Begin	Time End	Dir of Travel	Loc of Work	Time Begin	Time End	Dir of Travel	Loc of Clo-sure	# Lns Clsd	Time Q Starts	Time Q Ends	Q Lngth Hr 1	Q Lngth Hr 2	Q Lngth Hr 3	Q Lngth Hr 4	Q Lngth Hr 5	Q Lngth Hr 6

Notes:

Estimates of queue lengths approximately every hour are desired. However, the time can be adjusted slightly as necessary, as long as the reporting time is noted.

Locations of work and lane closures can be noted using mile markers, stations, etc.

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