Work Zone Performance Measurement Using Probe Data

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16. Abstract

This report assesses the potential for probe data to support work zone performance measurement programs. It includes an overview of probe data and the advantages and disadvantages of probe data sources relative to traditional fixed sensors. It identifies when and how probe data sources can be used to support work zone performance measures. It also characterizes the applicability of different types of probe data to help manage different types of work zones.

The report then exemplifies this information by presenting summaries of projects that made use of probe data for work zone performance measures or examined the capabilities and limitations of probe vehicle data. A particular focus was on a recent Maryland State Highway Administration project that provided a comprehensive example of the use of probe data sources to compute the performance measures by developing a web-based work zone performance measure application.

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Executive Summary

Work zones present problems when it comes to performance measures since, by definition, they are not fixed in space or time. This reduces the value of data generated by traditional fixed sensors – fixed sensors may not be located where needed to monitor work zone traffic or may be out of service because of work zone activities. Probe data provides an alternate means of obtaining data on work zone traffic conditions to support work zone performance measures by gathering data directly from moving vehicles. This probe data can either be collected directly (e.g., by placing Bluetooth detectors at key locations) or obtained from a number of commercial providers that specialize in the collection and distribution of probe data.

The potential for probe data to improve work zone performance measurement is significant; but, implementation is not easy. Commercial probe data providers have focused on probe data products for normal traffic management operations and have little experience with the data needs specific to work zones. Most work zone practitioners have limited experience with probe data. Consequently, knowledge of the ability of probe data to support work zone management needs is limited. This report aims to address these problems and provide practical guidance to work zone program managers on how to take advantage of probe data resources to support their work zone performance measure needs. Topics covered include:

- An overview of probe data and the advantages and disadvantages of probe data sources relative to traditional fixed sensors.
- Identification of when and how to use probe data sources to support work zone performance measures, including identifying which work zone performance measures can be supported by different types of probe data sources.
- Characterization of the applicability of different types of probe data to help manage different types of work zones.

The report also includes a detailed case study of a pilot project conducted by the University of Maryland Center for Advanced Transportation Technology for Maryland State Highway Administration. This pilot project assessed the adequacy of available probe data sources to support work zone performance measures and implemented a web-based system that uses probe data to assess work zone performance measures. This project provides detailed examples of performance measures produced from probe data.

The last part of the report provides overviews of a number of other projects and activities that either used probe data for work zones or assessed characteristics of probe data that might be helpful to work zone practitioners. Appendices provide information on (a) the future of probe data and how the evolution of probe data will impact its applicability to work zone performance measures and (b) simulation results that investigate the effectiveness of Bluetooth detectors as a source of work zone traffic data.

There have been numerous successful examples of using probe data to support work zone performance measures. Most of these examples focus on using probe data to measure work zone travel times, though there are also examples of using probe data to help monitor queue formation and to detect changes in route choice. The net result suggests that the time has come for work zone practitioners to consider taking advantage of probe data sources.

1. Introduction

1.1 Background

Performance measures establish quantitative measures for assessing an organization's performance. Establishing and estimating performance measures is an important first step in improving organizational performance – performance measures provide the basis for quantitatively comparing current and past performance to help determine if process changes are improving performance. In fact, the act of establishing performance measures helps an organization focus on improving performance by encouraging the organization's staff to focus on improving those measures.

In September 2004, the Federal Highway Administration (FHWA) updated the work zone regulations at 23 CFR 630 Subpart J to encourage the collection and use of work zone safety and mobility data, stating that:

- States shall use field observations, available work zone crash data, and operational information to manage work zone impacts for specific projects during implementation.
- States shall continually pursue improvement of work zone safety and mobility by analyzing work zone crash and operational data from multiple projects to improve State processes and procedures.

In other words, the rule implies that agencies should use data to generate performance measures at the project and process levels in order to improve both the safety and mobility of work zones. FHWA's guidance document on implementing this rule[1] makes this implication more concrete by recommending the application of performance measures in four areas of interest: safety, mobility, construction efficiency and effectiveness, and public perception and satisfaction.

Work zones present challenges when it comes to collecting data for mobility performance measures since, by definition, work zones are not fixed in space or time. Traditional fixed sensors are often not located where needed to support work zone performance measures and sensors that are located in a work zone may be out of service because of work zone activities. Because a work zone is temporary, it may not be cost-effective to deploy traditional fixed sensors specifically to support work zone performance measures. Even at a large, long-term work zone where it could be cost-effective to deploy traditional fixed sensors, the location of work within the work zone may vary from day to day, making it difficult to identify appropriate locations at which to deploy sensors. Even when these challenges are overcome, there can be biases in the resulting performance measures because data is more likely available from work zones in urban areas (where fixed sensors are more likely to be available) and larger work zones (in which the larger potential impacts make the collection of traffic data more likely).

Recent advances in probe data technologies provide the potential to overcome many of these challenges. Some probe vehicle technologies (e.g., Bluetooth detectors) are inexpensive to deploy and easy to move, allowing an agency to cost-effectively monitor work zone traffic at specific work zones. Several commercial vendors of mobile traffic data now provide nationwide traffic data coverage based on probe data sources. This provides the potential to use a single, uniform source of data that can be used to support performance measures across all work zones in a State.

[1] Implementing the Rule on Work Zone Safety and Mobility (23 CFR 630 Subpart J), FHWA-HOP-05-065. Available at http://ops.fhwa.dot.gov/wz/rule_guide/. (Verified 7/25/2013.)

Several organizations have already begun to take advantage of this potential. Some have deployed probe based data collection systems to monitor work zone traffic. Others have developed work zone performance measurement systems that leverage probe data available from commercial vendors. The purpose of this report is to help other organizations take advantage of the potential for probe data to support work zone performance measurement programs by (a) providing guidance for using probe data for work zone performance measures and (b) describing the experiences and lessons learned from organizations that have begun doing so.

1.2 Work Zone Traffic Impacts and Mobility Performance Measures

Generally, the mobility problems associated with a significant work zone project include:

- Increase in congestion due to reduced speed limits, narrowed lanes, and lane closures.
- Increase in congestion caused by work zone related crashes, which can result from increased friction in traffic flow (e.g., at lane closure merge areas) and unexpected queues resulting from work zones.
- Reduced access to businesses and/or special events.

Safety problems associated with work zone projects include worker safety, decrease in road safety, and, where applicable, decrease in pedestrian safety.

Several agencies have been successful in using safety and mobility performance measures to assess their performance in these areas, to identify deficiencies or gaps in their approach to project delivery, and to make improvements. Some performance measures are used programmatically to assess the extent to which policies, processes, and procedures are working to limit safety and mobility impacts of work zones. A common example is the number of work zone crashes and worker accidents used to assess work zone safety. Other performance measures are used at a project level to assess the performance of an individual project and to provide the opportunity to implement project-specific mitigation steps if expected performance levels are not being met. For example, a mobility measure such as average travel time through a work zone could be monitored and mitigation steps taken if the work zone travel time exceeds a pre-defined threshold.

Probe data is a potential source of performance data for work zone mobility performance measures.

Because probe data is most useful for assessing mobility measures, this report focuses on mobility measures. The literature further divides the data needs for work zone mobility performance measures into three categories: (1) performance data, (2) exposure data, and (3) indicator or stratification data. This is the specific focus of this report – the use of probe data as a source of performance data for work zone mobility performance measures.

The literature also describes a number of specific performance measures for measuring work zone mobility:

- Delay per vehicle
- Queue length
- Duration of queue
- Volume to capacity ratio
- Level of service
- Volume/throughput
- Percent of time operating at free-flow speeds
- Percent of work zones meeting expectations for traffic flow
- User complaints

Probe data can be useful for assessing most of these performance measures. (Section 2 of this report provides detailed guidance on using probe data to assess mobility performance measures.)

1.3 Introduction to Probe Data for Work Zone Mobility Performance Measures

In general, probe data is defined as data that is generated and collected from moving vehicles, with the objective of measuring certain performance characteristics at the location of individual vehicles. Traditional approaches to traffic data collection involve the use of roadside infrastructure to collect traffic data (e.g., speed, volume, occupancy) from passing vehicles. In some cases – typically to support research rather than traffic operations – this data was supplemented by probe data in which vehicles driven by researchers drove through the study area and recorded time-stamped information about the vehicle's position.

In the past few decades, the evolution of telecommunications and wireless technologies has opened up a world of opportunity to collect traffic data in alternative ways. These technologies support probe-based systems that rely on using increasingly ubiquitous Bluetooth devices to identify vehicles, Global Positioning System (GPS) technologies, or cellular location systems. These offer broader coverage, with the potential to cover major arterials.

Mobile data exists in different forms, with different contents, and can be collected in different ways. Mobile data can be categorized into three major classes, based on the data collection methods used:

1. **Floating car data collected by electronic transponders**. In this method, electronic transponders (tags) are placed on vehicles and electronic devices for reading those tags are placed along the roadway to determine when each vehicle passes those locations. The Automotive Vehicle Identification (AVI) technique is one such example which is covered widely in the literature [1]. Other examples include electronic toll data collected at toll booths, Bluetooth data collected by roadside Bluetooth receivers, etc.

Figure 1. An Example of a Roadside Bluetooth Detector

Source: Photo provided by BlueToad.

2. **GPS based mobile data**. In this case, probe vehicles are equipped with GPS receivers that determine vehicle position from signals received from earth-orbiting satellites. The positional information determined from the GPS signals is transmitted to a control center to display real-time position of the probe vehicles. Usually GPS mobile data mainly come from certain types of

vehicles, particularly fleet management services (e.g., taxis and trucks). The Connected Vehicle program conducted by U.S. DOT is now offering a new opportunity for collecting GPS based mobile data.

3. **Cell phone based mobile data**. With this type of system, every switched-on mobile phone becomes a traffic probe in the network. The location of the mobile phone is usually determined by means of triangulation or by the hand-over data stored by the network operator, so cell phone system can provide time stamped information on vehicle locations. This information can be translated into road segment travel times. In contrast to the first two categories, cell phone based mobile data requires no hardware in cars and no specific infrastructure needs to be built along the road.

Overall, mobile data differ dramatically in nature from traditional fixed sensor data. The advantages and some shortcomings of mobile data are summarized in Table 1.

Table 1. Pros and Cons of Mobile Data for Work Zone Performance Measures

Advantages	Disadvantages
• Low or no cost in installation and maintenance • Wide geographic coverage (freeways and arterials) • Finer resolution (individual vehicle and shorter measurement time interval) • Includes travel time information • Not affected by traffic interruptions or bad weather conditions • Can provide details on roads without fixed sensors currently in place • Can provide accurate real time information to reflect shifts in routes and origins and destinations • Provides ability to assess impacts of operational changes before and after work zone actions	• Less experience with analyzing data • Technology is not as mature as fixed sensors • No occupancy or traffic density information

These unique properties of mobile data make it practical to be incorporated into traffic analysis and help improve the accuracy and relevance of work zone monitoring.

These differences in the nature of mobile data have also resulted in differences in how traffic data is obtained. Traditionally, each agency was responsible for obtaining traffic data along the roadways they managed, deploying and maintaining sensors where needed in order to do so. Several companies are now taking advantage of probe data to provide traffic data as a commercial service. These services often provide capabilities that differ from those of traditional traffic monitoring.

Probe data, then, provides two basic approaches for improving work zone mobility performance measures:

1. Inexpensive roadside detectors (e.g., Bluetooth) can be deployed to collect traffic data for specific work zones. The primary benefits of this approach are that the detectors are relatively

inexpensive and easy to relocated and produce travel time data, which is difficult to produce with traditional traffic monitoring techniques.

2. Traffic data from commercial vendors can be used across all work zones within the geographic coverage of the vendor. The primary benefit of this approach is more uniform coverage across all work zones and availability of more detailed data both within the work zone and on nearby roads. The cost can also be low, particularly for States that are already contracting for probe data from a commercial vendor.

But, there are also disadvantages and limitations. The data available is often limited to travel times and the technologies and analysis techniques involved are not as mature as with fixed sensors. These advantages and disadvantages will be examined in more detail in the remainder of this report.

1.4 Document Overview

This report consists of three major sections:

1. This section introduces the reader to the topics of work zone performance measures and the use of probe data to support those performance measures.
2. The second section provides a more detailed description of probe data and guidance on how to use probe data for work zone performance measures.
3. The third section includes case studies of several recent applications of probe data for work zone performance measures.

The report includes two appendices. The first describes the future of probe data and the second summarizes results of a simulation study on the use of Bluetooth to estimate queue length.

2. Guidance for Using Probe Data for Work Zone Mobility Performance Measures

2.1 What is Probe Data?

Probe data is defined as data that is generated by monitoring the position of individual vehicles (i.e., probes) over space and time rather than measuring characteristics of vehicles or groups of vehicles at a specific place and time. Probe data systems can be further characterized according to whether (a) they require additional roadside or vehicular infrastructure to support them or take advantage of existing infrastructure in innovative ways, (b) they produce detailed tracks of vehicle movements or only identify vehicle arrival at select points, and (c) they provide data in near real-time or only with significant delay. Table 2 summarizes different types of probe data collection systems that are currently available.

Table 2. Different Types of Probe Data Collection Systems

Type of Probe Data Collection System	Description
Probe Vehicle Runs	This is the original form of probe data measurement in which a vehicle driven by researchers is driven along a route of interest and records the vehicle position and time at either selected positions or time intervals along the route. In terms of the above characteristics, the method (a) requires vehicular infrastructure (the probe vehicle), (b) produces detailed tracks of the vehicles movements along the route, and (c) does not provide data in real-time.
Bluetooth Readers	This form of probe data measurement involves placing roadside detectors that identify passing vehicle by a unique identifier broadcast by Bluetooth devices (e.g., cell phones) that are onboard the vehicle. Travel time measurements are obtained by comparing vehicle arrival times at different readers. The method (a) requires roadside infrastructure, (b) does not produce detailed tracks of vehicle movements, and (c) can provide data in near real-time if the Bluetooth readers are equipped with networking capabilities.
Toll Tag Readers, License Plate Readers	This form of probe data measurement is similar to the Bluetooth Reader system described above, but identifies vehicles by detecting the unique IDs broadcast by toll tag transponders or using character recognition to determine license plate numbers. Toll tag readers that take advantage of readers at existing toll plazas, rather than additional readers placed specifically for travel time measurement, differ in that they do not require additional roadside infrastructure.

Type of Probe Data Collection System	Description
Automatic Vehicle Location (AVL)	This form of probe data measurement requires a GPS device in a vehicle that tracks the vehicle's position and periodically transmits information about recent vehicle movements or the vehicle's current location to a server for analysis. This technology is most commonly used for fleet management (e.g., buses, taxis, commercial vehicles). The method (a) does not require deploying infrastructure (assuming the AVL system is already in place), (b) can produce detailed tracks of vehicle movements (but may not, depending on the design of the AVL), and (c) can provide data in near real-time. The GPS technology used also allows measuring the vehicle's speed and direction of travel, in addition to its position.
GPS Mobile Devices	This form of probe data measurement is similar to AVL, except occurs on vehicles equipped with GPS mobile devices that are not part of an AVL fleet management system. For example, smart phone applications have been developed that provide probe data from the smart phone. Some onboard navigation systems also include this capability.
Cell Phone Tracking	This form of probe data measurement involves tracking vehicle movements based on the radio signal transmitted by cell phones. Each cell phone periodically emits a signal that identifies the phone and associates the phone with a geographic "cell," giving a rough geographic location for the phone. The cell phone system can use data from the signal received at several cell towers to get a more accurate location for the phone. This position information can be retained to generate a track of the phone's (and, by inference, a vehicle's) movement. The method (a) does not require deploying new infrastructure, (b) can produce detailed tracks of vehicle movements, and (c) can provide data in near real-time.

A probe data system converts these measurements of a vehicle's position and time into performance measures. The most commonly provided performance measure is the average travel time for a pre-defined road segment. The travel time for each vehicle passing over a road segment is estimated by subtracting the time when the vehicle arrives at the end point of the segment to the time when the vehicle left the start point of the segment. The average travel time is computed by processing these vehicle travel times to remove outliers (e.g., long travel times caused when a vehicle diverts from the road segment) and averaging the remaining vehicle travel times.

The work zone delay can be computed from the vehicle travel times by comparing the vehicle travel times when the work zone is present to travel times measured before the work zone was present.

In theory, other performance measures could also be calculated from probe data, but current probe data systems seldom do so. For example, queue length could be estimated by examining vehicle tracks to identify locations where vehicle speeds are low, indicating the vehicle was in a queue. Measuring queue length would require that the probe data system produce a detailed track of the vehicle positions – a Bluetooth system that only identified vehicles as they entered and exited a work zone could not directly measure queue length. The probe data system would also need to have a sufficient number of probes passing through the work zone to accurately identify the entry and exit points of the queue.[2] A system capable of measuring queue length would also be capable of measuring queue duration.

Some probe data systems can also produce estimates for vehicle speeds at positions within a work zone. Systems that rely on GPS to measure vehicle position automatically have access to vehicle speed data – this is one of the values provided by GPS. If a probe data system provides a detailed track of position data, then the vehicle speed can be estimated by comparing the position and time of two adjacent position observations. These vehicle speed estimates can be combined to compute the percent the percent of time that work zone traffic is operating at free-flow speeds. Probe data systems are not applicable for estimating some work zone mobility performance measures, such as volume to capacity ratio, volume / throughput, and user complaints.

In practice, probe data vendor companies sometimes combine data from multiple sources, including historical data, to enhance the quality of the data they provide. For example, historical data might be used to fill in gaps when little or no probe data is available. While this increases the overall quality of the traffic data under normal conditions, it can introduce limitations when applied to work zones because the historical data may not be applicable under work zone conditions. The exact algorithms and data sources used by the probe vendor companies to generate traffic data are considered proprietary, so any limitations that may exist when applying the data to work zones is difficult to predict. Some of the case studies described in Section 3 of this report include assessments of the adequacy of probe data sources for work zone performance measures.

2.2 What Work Zone Mobility Performance Measures can be Supported with Probe Data

One factor that impacts the applicability of probe data for work zone performance measures is the size and scope of the work zone and the traffic impacts that are expected to result from it. Four work zone types have been defined based on the expected impact a work zone will have on travelers:[2]

- Type IV. A Type IV work zone is expected to have little or no impact on the traveling public. Examples include activities such as mowing and guardrail repair.
- Type III. A Type III work zone is expected to have a moderate impact on the traveling public. Examples include activities such as shoulder repairs and repaving roadways with moderate traffic.
- Type II. A Type II work zone is expected to impact travelers at the regional and metropolitan levels. Examples include major corridor reconstruction and major bridge repair.
- Type I. A Type I work zone is expected to impact travelers at the metropolitan, regional, or interstate levels over extended periods of time. Examples include the Woodrow Wilson Bridge replacement in the Metropolitan Washington, DC area.

Probe data technologies are now a viable option for collecting data for work zone performance measures.

Table 3 represents suitable types of probe data that are appropriate for different types of work zones. Once the work zone affects travelers at a regional level (type I and II work zones), using GPS and cellular based probes that cover the entire region is the best approach. These types of probes can provide network-wide high resolution data. However, when the impact of a work zone is limited to a few segments, portable probes (e.g., Bluetooth sensors) become a viable alternative.

[2] Section 3.1 describes an alternate approach for estimating queue length based on travel time observations.

In fact, portable probes are more effective during off-peak period and in locations where other types of probe data are limited.

Table 3. Suitable Types of Probe Data to Manage Different Work Zone Types.

Probe Data Technology	Type I	Type II	Type III	Type IV
GPS Data	✓	✓	✓	✓
Cellular Data	✓	✓	✓	✓
Bluetooth Sensors	★	★	✓	✓

✓: Suitable as Main Data. ★: Suitable as Supplementary Data.

Table 4 presents the most common work zone performance measures and identifies the types of probe data that can be used to calculate each of those performance measures.

Table 4. Suitable Types of Probe Data to Calculate Different Work Zone Performance Measures

Probe Data Technology	Travel Time	Delay	Queue Length	Speed	Volume	Incidents	Cumulative Impact
GPS Data	✓	✓	✓	✓		✓	✓
Cellular Data	✓	✓	✓	✓		✓	✓
Bluetooth Sensors	✓	✓					

Based on this table, GPS and cellular based probe data provide the means to calculate many different performance measures, while portable probe data (e.g., collected using Bluetooth sensors) have relatively limited capability. However, relying on one type of probe data may not fulfill all of the project needs; and vendors usually supplement probe data with other types of data. In addition, the quality of the data can vary based on location, time of day, and several other factors. Therefore, a combination of data from conventional sensors, portable probe data sensors, and commercial probe data sources is essential to accurately monitor traffic perturbations and travel time variations in the work zone location. For instance, the probe data might not be considered a reliable source during off-peak hours due to the limited availability of probe vehicles; using Bluetooth detectors, conventional loop detectors, and historical data can improve the reliability of the data during these hours. Note that when probe data is not available and other technologies are not applicable, using historical data is the only remaining option.

An important limitation of probe data is that it cannot generally be used to estimate traffic volume, and supplementary data (*e.g.* loop detector data) is required to calculate this measure. The list below provides more detailed information on the application of probe data to each of the performance measures listed in Table 4.[2]

- **Travel Time and Delay** are the most straightforward measures to calculate from probe data. Most vendors provide real-time travel time data on a network-wide scale as well as for individual segments. Bluetooth sensors can also provide reliable travel time information between two points in a network. GPS and cellular based probe data can be more cost effective for large work zones as they do not have associated maintenance costs. Note that these measures can be very effective to reflect the effects of type I and II work zones on the regional network.
- **Queue Length** is another important measure which directly reflects the mobility performance at the work zone location. Once the speed of a probe vehicle drops below a pre-specified value while the next probe vehicle upstream has a reasonable speed, it can be concluded that the probe vehicle is in a queue. This requires data from individual probe vehicles. However, as the probe data does not cover the entire fleet over a segment, the queue length calculated based on this data is an estimation of the queue length. The accuracy of this estimation improves as the percentage of probe vehicles increases in the segment. The accuracy of the estimation also depends on the length of the segment for which the speed is provided. Most probe data from commercial vendors currently provide travel time information for Traffic Message Channel (TMC) code segments (see Section 2.4), which can be very long in rural areas and, therefore, queue length estimation can be inaccurate. It is expected that growing number of probe sources will soon allow customers to define their own segments and consequently, GPS and cellular based probes can be used to estimate queue length more accurately. The location of queue relative to the work zone location is also an important factor to consider. This measure can be used to investigate the impact of a work zone on the traffic upstream. In addition, the duration of queue can be determined based on the probe data which reflects another impact of work zone on travelers.
- **Speed** is an important mobility measure which is directly provided by the probe data vendors. Similar to travel time and delay, the average speed over a region can be calculated more accurately using GPS and cellular based probes. Bluetooth detectors can also provide average speed between two points in a network. When accurate disaggregate speed at a certain location is required, non-probe-based data collection may be required.
- **Volume** is a performance measure that reflects the amount of traffic exposed to any negative impacts of the work zone. Because probe data systems only provide data for a sample of vehicles, no current probe data system provides volume data. If volume data is required, other data collection methods may be required.
- **Number of Incidents** in the work zone location is a work zone safety performance measure which also affects other mobility measures described in this report. An incident can be inferred using probe data from the irregular traffic patterns it creates. However, the exact source of the irregular traffic pattern cannot be detected using probe data; therefore, other data sources (*e.g.* CCTV cameras, police reports, etc.) should be incorporated in the analysis. Note that this measure is not often used in real-time and should instead be used as a long term safety measure. The short term impact of an incident on mobility measures is, however, still important.
- **Cumulative Impact** refers to evaluating the impact of multiple work zone projects within a region or a corridor. The impact of multiple projects on the traffic pattern can significantly exceed the impact of individual work zones. GPS and cellular based probe data, because they provide data network-wide, can be used to investigate the cumulative impact of several work

zone projects on the regions' mobility. Note that the percent of work zones meeting expectations for traffic flow can be also evaluated using this measure.

2.3 How is Probe Data Collected, and by Whom?

There are two primary ways in which work zone probe data is collected: (1) by agencies or agency contractors collecting probe data to support work zone traffic management or performance measures for a specific work zone and (2) by third party companies collecting probe data to produce commercial traffic data products. The first type of work zone data collection is similar to traditional work zone traffic monitoring and does not require much additional explanation. The remainder of this section focuses on the second type and provides summary information on the largest vendors of mobile traffic data currently active in the United States that claim to have traffic data on a national scale: Inrix; TomTom; AirSage and NAVTEQ (a subsidiary of Nokia). Table 2 presents the overview and characteristics of the probe data provided by these vendors. Despite considerable progress, many parts of this market are still at an early stage of development. This means that certain key variables (price, for example) are not standard and vary based on market conditions. To date, most mobile data firms have focused on traffic information that supports navigation systems or 511 systems and do not have produces specifically tailored for work zone performance measures.

Vendors acquire the raw data from several data sources. These data sources include GPS data from fleet management companies that track individual vehicles (fleet can include trucks, light commercial vehicles, and taxis), navigation data from private vehicles, cell phone applications, cell phone locations, fixed sensors (operated and maintained by the data provider, other providers, or other agencies), and commercial devices [1].

The acquired raw data is then aggregated and anonymized. However, the level of aggregation varies among different vendors, with typical aggregation levels ranging from 15 to 60 minutes [1]. In fact, a vendor should consider the availability and aggregation level of different data sources in selecting the aggregation interval. In addition to the network wide aggregate data, most of the vendors provide individual data points for a selected segment and a time period. Network wide historical data is also provided by all vendors [1].

Table 5: Overview of Probe Data Vendors

Mobile Traffic Data Sources	Technology Used	Traffic Data Elements Collected	O-D / Trajectory Data and Point Data Availability	Real Time and Historical Data Availability	Location-Codes Used	Other information
Inrix	Commercial GPS data, DOT sensor data, and other proprietary data sources. GPS-enabled vehicles	Speed Travel Time	Point	R, H	TMC Codes	Data available for TMC road functional classes FC1, FC2, FC3, and some FC4; Flexibility in data format / levels of aggregation for up to latest 90 days
TomTom	TomTom devices (GPS) Data from the Vodafone mobile phone network (GSM) Data from governments and traffic control centers	Speed Travel Time	Point, Trajectory Origin-Destination	R, H	TMC Codes, Proprietary Segment Tables	
NAVTEQ	State of the art probe data processing including both point and route-based observations (Cellular) Data from NAVTEQ's proprietary sensor network	Speed Travel Time Volume from own sensors	Point	R, H	TMC Codes, Proprietary Segment Tables	
AirSage	Wireless signaling data, Cell phone GPS, Other Carrier Data	Date and timestamp, Mode, Speed, Travel Time, Location ID, Alert	Point, Origin-Destination	R, H	TMC Codes	Data available for TMC FC1-FC4; O-D data available in blocks as small as 1,000 sq.m. [fast becoming their most popular product, latest application an O-D study for LA-Las Vegas hi speed rail];
TrafficCast	Information derived from GPS tracking data, public sensors and reports of accidents, road works and weather reports. **B**luetooth Travel-time Origination and Destination devices.	Speed Travel Time	Point, Limited trajectory data depending on Bluetooth deployment configuration Origin-Destination	R, H	TMC Codes	

2.4 Are There Specific Probe Data technical Issues to Consider?

Although using probe data provides certain advantages over conventional data collection methods, the current practice in providing probe data faces certain challenges and limitations. The presentation of probe data on a geographical map is a challenge for vendors and users of this data. Basically, probe data is aggregated and provided based on a Traffic Message Channel (TMC) location referencing system. TMC segments are defined and managed by Nokia and TomTom. These segments vary in length based on the density of the roadway network. This criterion creates short segments in urban areas (the length of a block) and very long segments in rural areas (the distance between two interchanges). Therefore, information on a work zone segment shorter than the entire TMC segment can be distorted.

Some probe data vendors provide more detail within TMC codes which helps to differentiate whether delays are closer to one end of the TMC segment or the other. Note that another referencing system is Open Location Reference (OLR) which does not assign the location to TMC segments, and therefore offers more flexibility in presenting speed information. The selected segment in this system can align with the physical location of the work zone.

The aggregation time interval of probe data also presents another challenge to work zone management. Work zone management and operation control require real time data with short aggregation time intervals to monitor queue formation and propagation, current travel time, and incident occurrence. Short aggregation time interval data also provides more reliable base data for predicting traffic evolutions over time and space. However, a shorter aggregation time means a smaller sample size for the aggregated estimates, which means less accurate estimates.

To date, most vendors use 15 or 60 minutes aggregation time interval which smooth out minor fluctuation is traffic flow, speed and density as well as travel time. This time interval can be too long to identify quickly changing characteristics like can be associated with work zones. The simulation results in Appendix B show a queue expanding from 0 to 200 feet in 5 minutes time, then dissipating in the succeeding 10 minutes. Even a 15-minute aggregation period would miss key characteristics of this type of work zone queue formation. The Maryland State Highway Administration project (see Section 3.1) also identified data lag (*e.g.* the difference between the time of actual speed perturbations in the field and the time that the perturbation is reported in the data) as a challenge in using probe data.

Probe data is expected to represent the overall traffic in a segment. Therefore, the percent of vehicles acting as probe vehicles becomes an important challenge to incorporate probe data into work zone management and operation. Sample size varies based on the technology (GPS, cellular, Bluetooth, etc.) used by the firm that provides the data, time of day, and location. Thus the volume of data provided by the probes may not be adequate to represent the entire fleet at a segment especially during off-peak hours and in arterials. Note that the volume of probe data is increasing rapidly so the extent and nature of these problems should improve over time.

2.5 When is the Use of Probe Data Worth Considering?

Work zone management includes timely decision making to reduce the impact of the work zone on travelers. This task requires accurate information about the current status of the traffic in the work zone vicinity. Probe data can provide this information on a real time basis. However, several factors should be considered when selecting probe data as the source of information.

> ***Factors that favor the use of probe data from commercial vendors include the need for programmatic performance measures, availability of data acquired for other reasons, and the need for detailed data over a broad area or a long period of time.***

- **Performance measure objectives**

  As already noted, there are many distinctions between the requirements for supporting programmatic performance measures to assess the mobility performance of a work zone program and project-specific performance measures for real-time monitoring of work zone mobility. For the former, third part probe data vendors provide perhaps the only cost-effective approach for mobility data that will uniformly apply to most work zones. For the second, many more options are available.

- **Availability of probe data**

  Two of the case study projects described in Section 3 of this report took advantage of real-time probe data that was purchased for other reasons to support work zone performance measurement activities. In Maryland (see Section 3.1), a real-time performance measure dashboard was developed that computed and displayed mobility performance measures for active work zones. In Virginia, archives of probe data was used to compute travel time reliability measures for 15 work zones. Another example comes from the Utah Department of Transportation, which recently purchased access to historical probe data in order to assess the potential to use the data for a variety of purposes, including improving traffic signal timing plans and computing performance measures. When probe data has already been purchased to support other DOT objectives (e.g., to provide traveler information), it can greatly decrease the cost of establishing performance measure programs for work zones.

  Note that licensing restrictions apply to most probe data obtained from probe data vendors. These restrictions may limit the application of the data or its distribution. Before re-using probe data obtained for another purpose, the licensing restrictions under which the probe data was obtained must be considered.

- **Nature of the task**

  The nature of the task determines the data required. If the task requires detailed information on traffic evolutions in real time, the use of probe data is inevitable. For instance, real time monitoring of a work zone, real time management of traffic conditions in a work zone location, and responding to public in real time (providing travel time, delay, and speed to public) require accurate information on the traffic evolutions along that work zone segment. On the other hand, when all the necessary information can be obtained from conventional sensors and/or historical data, the cost of acquiring the probe data is a preventing factor. For instance, monitoring spot speed along a work zone at a defined location can be obtained from conventional sensors.

- **Duration of the work zone**

  Considering the cost of acquiring the probe data, monitoring work zones that affect travelers for a very short period may not be cost effective. In addition, based on the duration of the work zone, different types of probe data might be suitable. Longer durations require more robust technologies with minimal maintenance effort. Therefore, GPS based and cellular based probe data is more appropriate for longer durations and using Bluetooth detectors is more appropriate for shorter durations. This factor is less important when probe data has already been purchased to support other DOT activities.

- **Scale of work zone impacts on traffic disruptions and local surroundings**

  The scale of work zone impacts also is an important decision factor in selecting the most appropriate type of probe data. The potential for large traffic disturbances justifies close monitoring of the traffic performance in the impacted area, which may require the use of GPS and/or cellular based probe data. On the other hand, when a work zone is expected to have minimal impact on traffic, monitoring the area using probe vehicle data may not be justified, considering the cost of acquiring that data.

  The existence of multiple work zones along a corridor or nearby routes can also justify the use of probe data. The cumulative effect of multiple work zones on a network can be significant and demands close monitoring of traffic disturbances.

  The scale of the likely impacts also affects the most suitable technology for collecting probe vehicle data. Monitoring a long corridor or a network using a system that requires point-based roadside infrastructure (e.g., Bluetooth) can be expensive because of the large number of detectors required. In those cases, an approach that does not rely on roadside infrastructure (e.g., GPS, cellular based probe data) may be more suitable.

- **Lack of conventional sensors**

  In locations with existing conventional sensors, the existing sensors may provide sufficient data about the work zone to satisfy work zone performance measure needs. When existing sensors are not available, probe-based methods can be a cost-effective alternative.

- **Availability of specialized software to compute performance measures**

  One of the objectives of the Maryland State Highway Administration project described in Section 3.1 was to develop work zone performance measurement software that was applicable to any location with access to real-time traffic monitoring data at work zones. Access to specialized software such as this can reduce the cost of establishing a work zone performance measurement program.

2.6 What Needs to be Done Before Using Probe Data for Work Zone Performance Measures?

Incorporating probe data into the work zone management and operation requires certain considerations. First is the need to obtain performance measures for the work zone, which will primarily depend on work zone policies and procedures. The question of whether performance measures are needed is outside the scope of this document, so the remainder of this section assumes that it has been determined that performance measures are needed for the work zone being considered.

The next question to consider is whether to use traditional traffic detection, infrastructure-based probe data detection (e.g., Bluetooth detectors), or probe data from a third party vendor. The previous section identified factors that should be considered when determining whether to use probe data and what type of probe data to use. The use of infrastructure-based probe data detection shares many characteristics with the traditional traffic detection with which work zone managers are already familiar. The application of probe data from third party vendors, however, offers some unique challenges. Figure 2 depicts a decision chart that can help determine when probe data from a third party vendor is a viable alternative to support work zone performance measures.

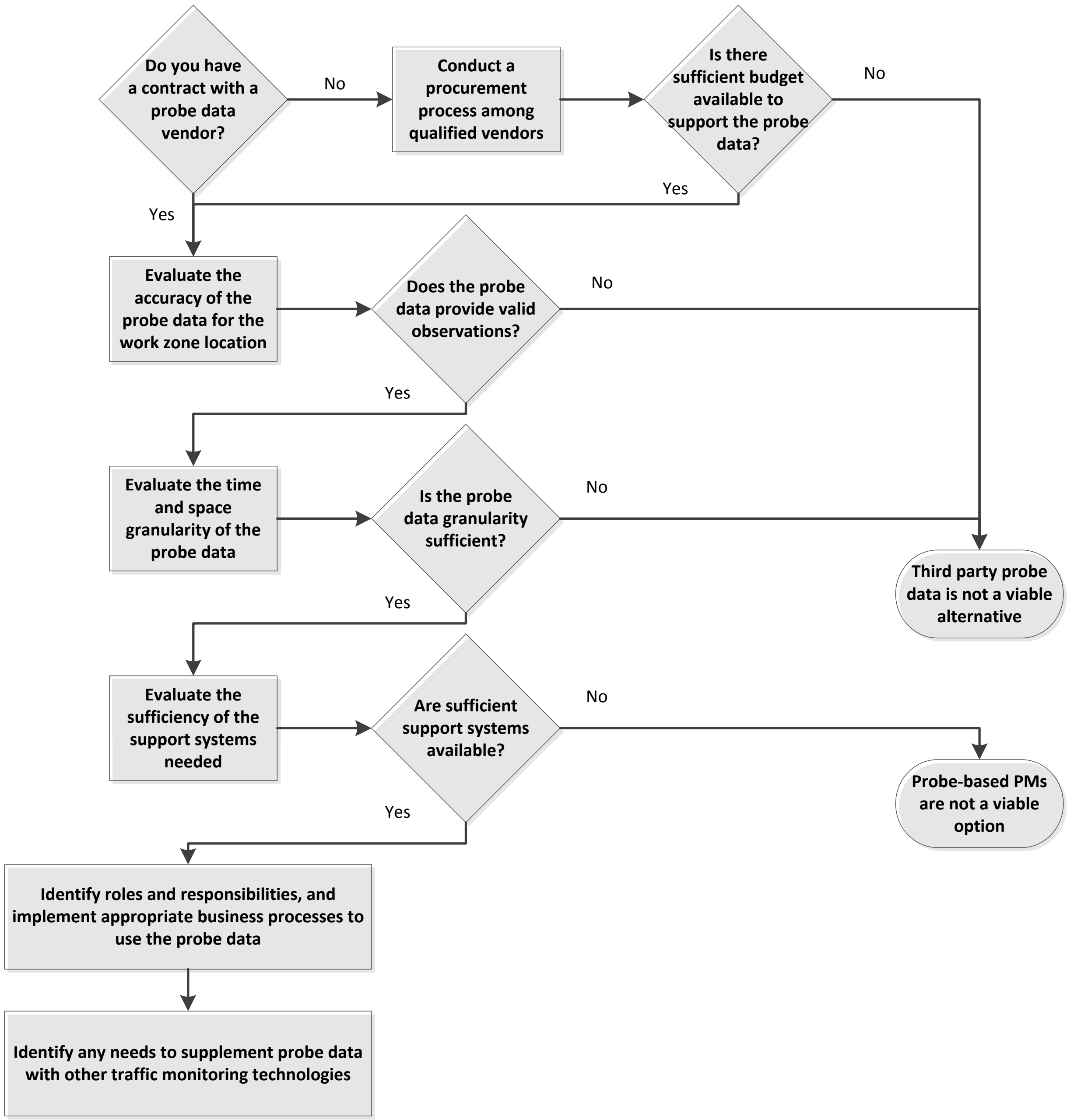

Figure 2. Decision Chart for Acquiring Probe Data from a Third Party Vendor

The first question is whether a contract exists for probe data and the probe data can be re-used for the work zone. If not, one must evaluate the cost of obtaining probe data. If data is available, the licensing agreement under which the probe data was obtained must be reviewed to verify that it can be used to support the work zone performance measures.

Next, the accuracy of the probe data at the work zone location should be evaluated. Note that the accuracy of the probe data can depend on the work zone location and the source of the probe data. For example, GPS-based probe data may rely on GPS data from commercial vehicles, so will be more accurate for work zone locations with more commercial vehicle traffic. The accuracy of most probe data systems will also vary by time of day because changes in traffic volumes over time result in different numbers of probe observations at different times of day. One might need to also consider work zone traffic management processes that will be put in place. For example, routing of commercial vehicle traffic around a work zone may significantly reduce the number of probe observations available. The extent to which historical data is used by the third party vendor in their travel time estimation process should be considered. Lessons learned during Virginia DOTs use of probe data for work zone performance measures (see Section 3.2) indicated that full road closures could result in an inaccurate picture of a work zone area. When no real-time data was available, historical observations were used that did not always agree with actual traffic conditions.

The time and space granularity of the available probe data must also be considered. If the segment size for which probe-based travel time data is available is too large or the time interval between travel time updates is too coarse, the third party probe data may not suffice to meet the performance measure needs. If all of the above constraints are met, then third-party probe data is a viable alternative for the work zone performance measures. But, there are additional steps that must be taken before third party probe data can be applied to the work zone.

The support systems – the computer hardware, software, and communication systems needed to receive, process, analyze, and broadcast information to intended users – must be sufficient. The business processes must be put in place to make use of the probe data, and the roles and responsibilities of those responsible for implementing those processes must be defined. Lastly, any needs to supplement the probe data (based on deficiencies identified in the previous evaluation steps) should be considered.

2.7 What Needs to be Done Before Using Probe Data for Programmatic Performance Measures?

As already noted, the decision for whether to apply probe data for programmatic performance measures is different than the decision for an individual work zone. Probe data from third party vendors, in particular, provides the potential to apply a uniform set of performance measure produced from a uniform set of data across most or all work zones in a State. This is a capability that is difficult to meet with other data sources.

Probe data from commercial vendors is particularly well-suited for computing a uniform set of performance measures across many different work zones.

Most of the considerations described in the previous section also apply when evaluating the potential for using probe data for programmatic performance measures. For example, if probe data is already available because of an existing contract with a third party probe data provider, then the cost of establishing programmatic performance based on probe data will be greatly reduced. When identifying whether sufficient support systems are available, the results of the Maryland State Highway Administration project described in Section 3.1 should be considered. This project created a work zone performance measure system that has the potential to be re-used in other States.

2.8 Design Considerations

The impact of work zones on traffic operations varies based on several factors including scale of activity in the work zone, road type, flow level, time of day, time of week, weather condition, and occurrence of special events or evacuation. Work zone traffic impacts can stretch far upstream of the work zone and even impact nearby roadways. Therefore, predicting and monitoring the impact of work zone on the traffic patterns and travel behavior are essential before and during the work zone operation. Probe data can provide the required accuracy and detail to monitor the traffic evolutions in real time along a corridor. However, as mentioned previously, probe data faces certain limitations including TMC based aggregation and long aggregation time interval. TMC segments may have start and/or end points that do not align with work zone limits. In addition, the long aggregation time interval may smooth out the short term fluctuations and disturbances. The limited availability of probe data at certain times and certain locations is another limiting factor and agencies may consider supplementary data (*e.g.* portable probes and historical data) for these times and locations.

Tools and techniques for using probe data to compute work zone performance measures are still evolving.

Work zone management and operation requires an automatic and robust system to collect, analyze, and archive performance data (and raw data if necessary) during the operation. The system should be able to later retrieve the required information based on specific agency needs. This task requires coordination between the agencies, their contractors, equipment suppliers, and other third party agencies. It also requires specific training, and agencies should consider all the required means in advance. Considering a central location with trained personnel specifically for this task may reduce the cost of collecting, analyzing, and archiving probe data over time.

Special considerations apply for systems that generate alerts when pre-determined conditions occur (e.g., work zone travel time exceeds a threshold value). Standardizing these alert notifications and the corresponding thresholds based on certain parameters (including scale of activity, type of road, location of the road, flow level, time of day, day of week, weather condition, and occurrence of special event or evacuation) is essential and provides the necessary means to compare the performance over multiple work zones. This is especially important when reporting alerts to the general public – in that case, it is necessary to provide consistent information. Therefore, a certain set of alerts should be determined to report to the general public regardless of work zone characteristics, location, and time of day. Alerts can vary based on the project objectives and other parameters.

In addition, alerts and corresponding thresholds should be customizable to a certain level based on the project needs and characteristics. For instance, a low maximum speed alert might be appropriate when workers are present at the work zone location, but unnecessary when workers are not present. It is also important to note that there should be a guideline for adjusting the thresholds to eliminate any misleading information. The Maryland SHA case study in Section 3.1 includes examples of a flexible system for managing alerts.

2.9 Institutional Considerations

In addition to the design considerations, incorporating the probe data into work zone management and operation can affect traditional institutional agreements. Conventional data is typically owned and managed by the governmental agency, which is not the case for probe data from a third party vendor. Instead, probe data from a third party vendor is provided with a "limited rights" license which limits the extent to which the governmental agency can distribute and share the data. Therefore, using probe data requires new client and contractor roles and responsibilities. The contractors' access to probe data (or at least the performance measures) should be granted in the contract with the probe data vendor and other contractors.

In addition, analyzing probe data in order to extract different performance measures requires certain expertise. The level of training depends on the agency's needs, and the necessary training should be performed before the start of the project. The contractors should also have a minimum level of training to utilize the probe data in their assigned tasks and to facilitate communication with governmental agencies and the probe data vendor.

Any work zone project that significantly affects the public will benefit from providing them with information. Offering accurate information to the public can help them adjust their travel behavior to avoid delays resulting from the work zone activity. Consequently, the governmental agency identifies the potential impact throughout the project duration and can implement effective strategies to mitigate the impacts [2]. In this regard, probe data can provide an excellent basis for providing real-time work zone traffic information to the public. However, this requires coordination with the probe data vendor to solve licensing issues, as well as some IT contractors which are responsible to create the user interface.

2.10 Reporting Considerations

In addition to improvements in work zone management and operation, availability of probe data enhances the quality of project reports. More accurate evaluation of work zone performance measures can be presented. However, standards are needed to enable consistent and meaningful comparison between different types of work zones. While providing more detailed information regarding the work zone operation, the analysis should be consistent with the reports that only use conventional data collection methods.

3. Case Studies

3.1 Maryland State Highway Administration

3.1.1 Background

Rationale for Project

This case study is based on a pilot project conducted by the University of Maryland (UMD) Center for Advanced Transportation Technology (CATT) and involves the development of a real-time performance monitoring tool specifically for work zones using data from the Regional Integrated Transportation Information System (RITIS). The Maryland State Highway Administration (MDSHA) recognized the opportunity to use probe data already integrated into RITIS to help measure work zone performance, as well as to improve planning and management of work zones, and contracted with CATT to help develop the proposed tool. The resulting work zone performance measure (WZPM) application will be able to both monitor a work zone in real-time and produce work zone performance measures based on historical data.

The WZPM application can help comply with assessments of work zone impacts on mobility and safety that are required by the Final Rule on Work Zone Safety and Mobility.

Part of the motivation for creating the tool was to help comply with requirements in the Final Rule on Work Zone Safety and Mobility that require state and local governments that receive federal-aid funding to assess work zone impacts on mobility and safety. SHA does not currently have formal work zone performance measurement processes in place. Therefore, this tool will give SHA the ability to obtain the necessary data and to measure and report work zone performance measures.

Research Objectives

This pilot project aims to accomplish a number of goals, including:

- Determine adequacy of third party probe data to support work zone performance measures
- Identify work zone performance measures and develop methodologies to assess them from available data
- Design a user interface “dashboard” that displays work zone performance measures in an effective manner
- Validate the work zone performance measures produced by the tool, both in terms of the accuracy of the performance measures and their adequacy to assess work zone performance

Throughout the project, input was gathered from potential MDSHA users to help identify ways to improve the proposed performance measures and the tool that produced and displayed them.

These objectives were pursued in the order presented in the list above, with the first objective listed was considered paramount – no other objectives could be achieved if the third party probe data was not adequate to support the needed performance measures.

Project Timeline

The UMD/CATT probe prototype project began in the fall of 2011 by identifying appropriate real-time and historical work zone performance measures and assessing the adequacy of probe data to support those performance measures. After appropriate performance measures were identified, UMD/CATT began designing a prototype user interface “dashboard” to display work zone performance measure information. This prototype dashboard was shown to potential users in October 2012 in order to obtain comments and suggestions for improvement. A second meeting with potential users was held in December 2012. In early 2013, UMD CATT began developing the WZPM application, which was available in prototype form in June 2013.

Data Sources

The WZPM application was developed around the data available in RITIS. The RITIS data covers a number of States and includes data from both fixed sensors and from a third party probe data provider. This is an important characteristic of the WZPM application – it can be readily adopted by any State that participates in RITIS and for which probe data is available.

The WZPM application can be readily adopted by any State that participates in RITIS.

3.1.2 Identifying Work Zone Mobility Performance Measures

One of the first steps in the UMD/CATT probe prototype project was identifying the work zone mobility performance measures that would be used. Three main mobility metrics were identified for work zones: delay, congestion, and queue length. These metrics were used as the basis for defining a number of programmatic performance metrics and for supporting an alert system. The remainder of this section describes these metrics and performance measures in more detail.

Defining a Work Zone

The UMD/CATT project decomposed a work zone into three segments: upstream, work area, and downstream, as shown in Figure 3. The work area is the area in which work is being performed. The work zone includes the area around the work area from the first warning of the work zone ahead (i.e., a warning sign or a flashing light on a vehicle) to either the "end of work zone" sign or the last work zone traffic control device. The work zone impact area consists of the work zone, plus the areas upstream and downstream of the work zone in which mobility and/or safety is impacted by the work zone. Work zone performance measures should be assessed over the work zone impact area, not just the work zone itself. In particular, the upstream and downstream areas should be large enough to capture shockwaves moving towards and away from the work zone.

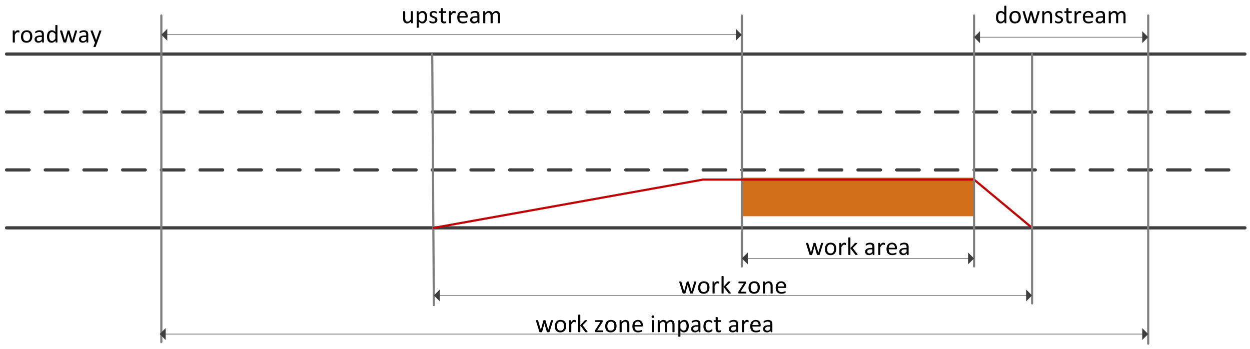

Figure 3. The UMD/CATT Probe Prototype Definition of Work Zone Segments

Work Zone Mobility Performance Measures

The work zone performance measures considered in the UMD/CATT project were based on the guidelines in a primer on the subject produced for FHWA [6] and included:

- Three basic mobility performance measures – delay, congestion, and queue length.

- Programmatic mobility performance measures that leverage the above performance measures, such as number of days with a queue, average queue duration, average queue length, maximum queue length, vehicle-hours of delay per work period, average delay per vehicle, etc.
- Alerts based on the basic performance measures, used to warn personnel that work zone mobility is below defined thresholds.

Approaches were defined to assess these performance measures from the RITIS probe data. These approaches are summarized in the topics below.

Delay
Vehicle work zone delay is defined as the time a vehicle spends in the area in which the work zone impacts traffic beyond what it would have spent under typical conditions for that date and time. Delay performance measures are computed by generating statistics based on the vehicle work zone delay. For example, the average delay is the average vehicle work zone delay computed over all vehicles exiting the work zone during a specified time period and the total delay is the sum of these vehicle work zone delay values. Probe data is particularly well suited for computing delay because travel time is a direct observation of most probe data systems.

Congestion
Congestion occurs when measured speeds (a) fall below historical speeds for the same location and time period and (b) fall well below a reference speed. Before this project, RITIS already included processes for identifying congested segments where the free flow speed was used for the reference speed and "well below" is defined as below 60 percent of the free flow speed. The UMD CATT team considered this definition as it applies to work zones and determined that it would be more appropriate to define "well below" for work zones as below 80 percent of the free flow speed. This conclusion was based on analyses that indicated a value of 80 percent could occur under either of the following two conditions:

- The congested portion of the work zone is more than half of the work zone length or
- The level of congestion in the congested portions of the work zone must be high, so that the level of service in the congested portion was LOS F.

When using probe data to measure congestion, the travel time observations generated by most probe data systems must be converted to speeds by taking the ratio of segment length to segment travel time. (Note that some probe data systems do report spot speed measurements, and it is anticipate that this may be more commonly available in future systems. See Appendix A for more information on the future of probe data.)

Queue Length
The UMD CATT team developed the following formula for estimating the work zone queue length based on the ratio of the observed average speed and the free flow speed.

$$\text{Min Queue Length} = \min\left\{2.03 * \left(\frac{1}{\propto} - 1\right), 1\right\} * \text{length}$$

In this formula, the term α represents the ration of the average segment speed to the free flow segment speed. This formula is based on defining the queued region within a work zone as the region in which the observed speeds are less than 67 percent of the free flow speed. This formula provides a mechanism for estimating queue length based on observations of average speed. This avoids the need to directly observe the queue, which is difficult because the position of the queue can change quickly over time.

Programmatic Work Zone Mobility Performance Measures
The UMD CATT team also identified a number of programmatic performance measures that could be computed based on the three mobility performance metrics described above. The first set of

performance measures only requires average speed or average travel time to compute. The general approach is to divide the day into intervals – typically the time interval for which the probe data vendor provides the data when probe data from a commercial vendor is being used. Delay is estimated directly from these travel times. The formula described above is used to estimate the length of the queue during each period. Queue events are identified by combining successive intervals with non-zero estimated queue length. The duration of each queue event is determined by the time period covered by the successive intervals that were combined. The queue length for a queue event is the maximum length of the queue during each event.

A number of programmatic performance measures can be computed from this information:

- Number of days when queuing occurred, computed by identifying the number of days during which a queue event occurred.
- Average queue duration, computed by averaging the duration of each queue event.
- Average queue length, computed by averaging the queue length for each queue event.
- Maximum queue length, computed by taking the maximum of the queue lengths for each queue event.
- Percent of time the queue length exceeds a specified threshold, computed by summing the interval lengths for the intervals for which the estimated queue length exceeds the specified threshold and dividing by the total time period for which observations were made.
- Maximum per-vehicle delay, computed by taking the maximum of the delay.

The second set of programmatic performance measures requires volume data, along with the travel time data available from probe data:

- Percent of traffic that encounters a queue, computed from the ratio of the sum of traffic volumes during queue events and total traffic volumes.
- Vehicle-hours of delay, computed by multiplying the average delay times the volume of vehicles that experience that delay.
- Average delay per entering vehicle, computed by averaging the delay values, weighted by the traffic volumes.
- Percent of traffic experiencing a delay that exceeds a defined threshold, computed from the ratio of the sum of traffic volumes for period where the average delay exceeds the threshold to the total traffic volume.

3.1.3 Verifying Work Zone Mobility Performance Measures

The UMD CATT team verified these performance measures by applying them to three work zones: on Westbound I-70, east of Frederick, Maryland; on Northbound I-795, near Baltimore; and on Southbound I-97, south of Baltimore. For each of these work zones, archived data from RITIS was used to compute the performance measures and alerts that would have been generated if the proposed system was available when the work zone was active. The report [4] includes detailed information on each of these work zones and describes lessons learned in applying the performance measures to these work zones. These lessons learned are summarized below.

Aligning Work Zone Boundaries with TMC Segments

The probe data available through RITIS provided travel time estimates for TMC code segments, so the first step in applying that data to work zones was identifying the relationship between the TMC segments and the work zone location. Table 6 lists these relationships for the Westbound I-70 work zone for a right shoulder lane closure that occurred on May 8, 2012. In this table, the first column indicates the name of a TMC segment and the second through fourth columns indicate the portion of the indicated segment that is contained in the upstream, work zone, and downstream areas, respectively.

The lack of alignment between the work zone boundaries and the TMC segments presents challenges when using third party probe data for work zone performance measures.

The first thing to note about the information in this table is that it is necessary to split the TMC segments so that the resulting segments align with the work zone boundaries. For example, TMC segment 110P04196 is sub-divided so that the first 0.60 miles are considered part of the upstream area and the remaining 0.12 miles are considered part of the work zone. The traffic condition information for the sub-segments is inferred from the traffic condition information of the parent TMC segment. The average speed of each of the sub-segments of TMC segment 110P04196 is assumed to be the same as for the parent TMC segment. The travel time for each segment is computed by dividing the length of the sub-segment by this average speed.

Table 6. TMC Segments for the Westbound I-70 Work Zone

TMC Segment	Upstream	Work Zone	Downstream
110+04489	3.45		
110+04467	1.13		
110P04195	0.63		
110+04196	4.85		
110P04196	0.60	0.12	
110+04197		3.33	
110P04197		0.03	
110+04198		2.15	1.20
110+04199			0.26
110P04199			0.19
110+04200			0.91

The large size of TMC segments, particularly in rural areas, may create problems when using commercial probe data for work zone performance measures.

A related problem has to do with the size of the TMC segments relative to the size of the work zones. In the example above, the longest TMC segment has a length of 4.85 miles. TMC segments in rural areas can be even longer. If the length of a work zone is considerably less than the length of the TMC segment(s) that contain it, then travel time and average speed information for the TMC segment may not provide an accurate characterization of traffic conditions within the work zone.

Computing Work Zone Performance Measures

These relationships between the TMC segments and the work zone areas allowed UMD CATT staff to use the probe data available from RITIS to compute the work zone performance measures for each of the work zones described above. The general approach was to compute the work zone metrics for each of the TMC segments related to the work zone area, then sum the segment-based performance measures to generate performance measures for the work zone. Table 7 lists the performance measures computed for the Westbound I-70 work zone during one 6 hour 34 minute period when the work zone was active.

Table 7. Performance Measures for the Westbound I-70 Work Zone

Performance Measure	Unit	Upstream	Work Zone	Downstream
Length	Mile	10.66	5.63	2.57
Average Delay	Minute	0.03	0.03	0.16
Maximum Delay	Minute	0.24	1.32	1.14
Queue Duration	Minute	330	135	394
Average Queue Length	Mile	0.06	0.06	0.34
Maximum Queue Length	Mile	0.52	2.15	2.04
Percent Time Queue Length Exceeded 1 Mile	%	0.00	0.25	2.03

Source: Table 10 of the UMD CATT PM Final Report [4]

Congestion performance measures were also computed. In this particular example, no congestion alerts were generated and the work zone areas were in congested conditions 0 percent of the time. Similar results were reported for the other work zones, though congestion alerts were sometimes generated for the other work zones.

The vehicle speeds through the work zone were reviewed and compared to historic values and vehicle delays were computed to obtain some insights into the extent to which the performance measures characterized the traffic conditions that actually existed. The only concern identified was with regards to the queue-related performance measures; even though only small delays were observed, the queue performance measures were large. Consequentially, an alternate method for estimating the queue length was tried. Rather than applying the queue length formula to each TMC segment and summing the resulting segment queue length estimates across the work zone areas, the TMC segment values were combined for each work zone area before applying the queue length formula. Table 8 shows the difference in the results from the two different approaches. The rows with the Method column listed as "Segment" are the performance metric values computed applying the queue length formula to the TMC segments, then summing across the work zone areas. The rows labeled as "Connected" are values computed by first computing average speeds for each work zone area, then applying the queue length formula.

Table 8. Comparison of Queue Performance Metrics Using Segment and Connected Queue Estimation

Performance Measure	Unit	Method	Upstream	Work Zone	Downstream
Queue Duration	Minute	Segment	330	135	394
		Connected	42	3	3
Average Queue Length	Mile	Segment	0.06	0.06	0.34
		Connected	0.00	0.00	0.00
Maximum Queue Length	Mile	Segment	0.52	2.15	2.04
		Connected	0.35	2.15	1.25

Based on these comparisons and similar comparisons for the other work zones considered, the UMD CATT team suggested that the "connected" approach resulted in a more stable measure of work zone queue lengths. The two methods produced similar results when estimating major queues. The first method often indicated the presence of minor, transient queue during times when the second method indicated no queue was present.

3.1.4 Displaying Work Zone Mobility Performance Measures

The UMD CATT team next developed a prototype dashboard display (see Figure 4) to summarize the mobility status of a work zone. This dashboard contains the following elements:

- The work zone name at the top left.
- A work zone activity summary on the left below the work zone name.
- A map of the work zone location to the right of the activity summary.
- A work zone speed summary at the bottom left.
- Work zone performance measure timelines at the top right.
- A speed heat map at the bottom right.

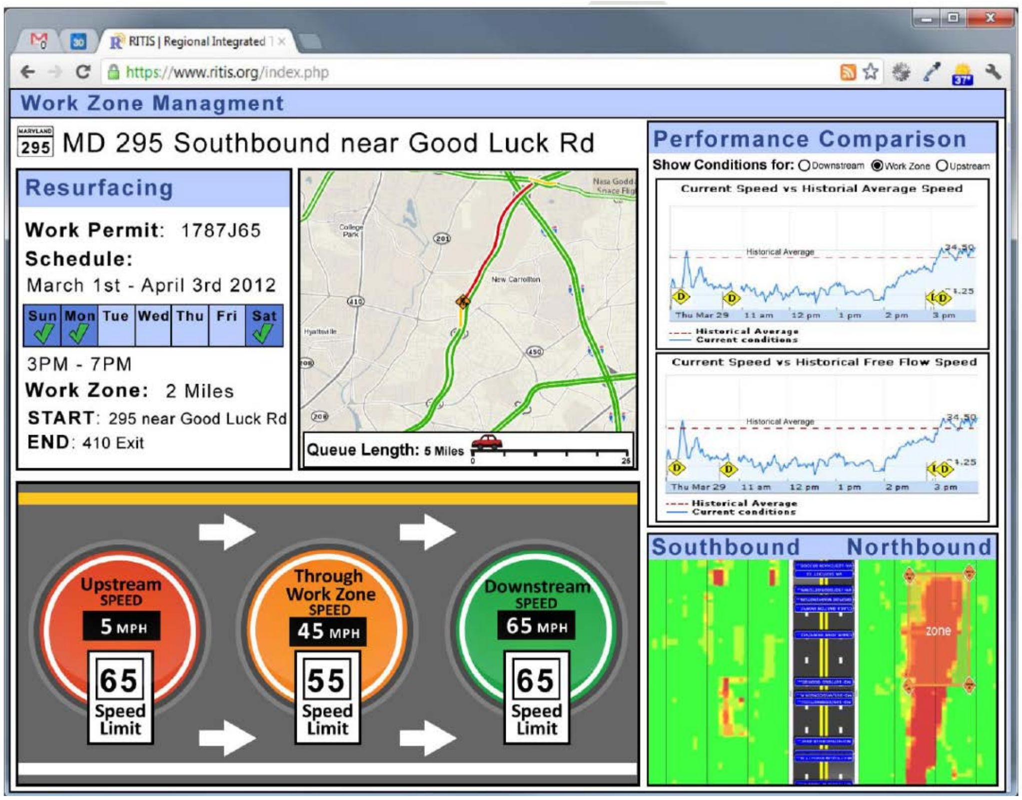

Figure 4. UMD/CATT Prototype Work Zone Performance Measure Application (Dashboard Concept)

Source: Figure 47 of the UMD CATT PM Final Report [4]

This dashboard concept was used for the purpose of gathering input from potential users on the elements contained within it, and did not rely on real-time data feeds. A simpler dashboard that only included the work zone speed summary was connected to a real-time data feed to demonstrate the general capability of supporting a real-time dashboard.

3.1.5 Obtaining User Input

A meeting was held on October 25, 2012 with potential users to get feedback on the work zone performance measures and the dashboard concept. A number of potential uses for the WZPM application were identified, including:

- Field staff could use the tool to facilitate oversight of construction activities.
- Public Information Officers could use the tool to provide information to the public and when responding to complaints.
- Traffic operations personnel could use the tool to monitor and respond to traffic conditions in work zones.

A number of suggested improvements to the WZPM application were also identified during the meeting.

WZPM application portability and accessibility is key
The application should be accessible on many different platforms, including desktop and notebook computers, tablets, and smart phones.

The WZPM application should show the real-time status of all work zones in the state
The dashboard concept focused on providing details for a single work zone. The suggestion was to provide a separate dashboard that provided a summary of all work zones.

The concept of alerts was viewed favorably, but might require some enhancements
Some suggested enhancements were to (a) enable the system to send automated text message, email, or voice mail alerts and (b) include incident information in the alert, when applicable.

The WZPM application should include access to weather and weather forecast information
Because of the potential for weather to impact work zone mobility performance, it was suggested that the WZPM application should include access to weather information, both when using the application to review real-time performance measures and to review historical performance measures.

Include a feature to facilitate comparisons of historical performance measures by day of week, months of year, etc.
This suggestion was focused on the ability of the WZPM application to support searches of archived data and provide capabilities such as comparing performance measures for a specified day of the week.

Participants also noted that the tool might be useful to other staff that were not represented at the meeting, including staff in construction engineering management, design/planning, and the Office of Traffic and Safety. So, a second meeting was held on December 13, 2012 to get feedback from potential user groups that did not participate in the first meeting. Some additional uses for the WZ PM application were identified, such as:

- The general public might find the tool useful, though the information available may have to be more limited and presented in a less technical manner.
- Public Information Officers might use the historic data to help them produce content for their monthly newsletters.
- The historic data could be useful when responding to contractors requesting an extension or change in their schedules.
- The historic data could be useful for preparing project documentation and bid documents.

Additional suggested improvements identified during this meeting include:

Include access to additional information
Work zone activity may have an impact on traffic, so it might be beneficial for the WZPM application to track where and when work zone activities are occurring. Displaying the work permit number and linking

to the permit database could be useful. Information on posted speed limits would be useful, particularly when responding to complaints.

Enhance the mapping capabilities
The map is useful to see the extent of the potential impact. The ability to zoom in and pan the map and switch between map and satellite views would be useful.

Integrate accident information
Including a search tool to find incidents that occurred during lane closures and other work zone activities would be useful.

Enhance customization
Different users have different needs, so it might be useful if each user could customize the dashboard to better suit their specific needs.

The users also identified some potential limitations of the system, including:

- Automatic Speed Enforcement (ASE) can result in reduced speeds in work zones and, therefore, impact mobility performance.
- Obtaining required inputs could be challenging. Project engineers do not have time to enter work zone parameters into the WZPM application. Much of the original work zone information is already entered into the Emergency Operations Reporting System (EORS). When lane and road closures result from an incident, no permit is required and information about the closure may be difficult to track.

3.1.6 The Prototype Work Zone Performance Measure Application

By May 2013, a prototype version of the work zone performance measures application was available that addressed comments received during the meetings with potential users. Figure 5 depicts a new feature that addresses the suggestion to provide a summary screen that showed the real-time status of all the active work zones in the State.

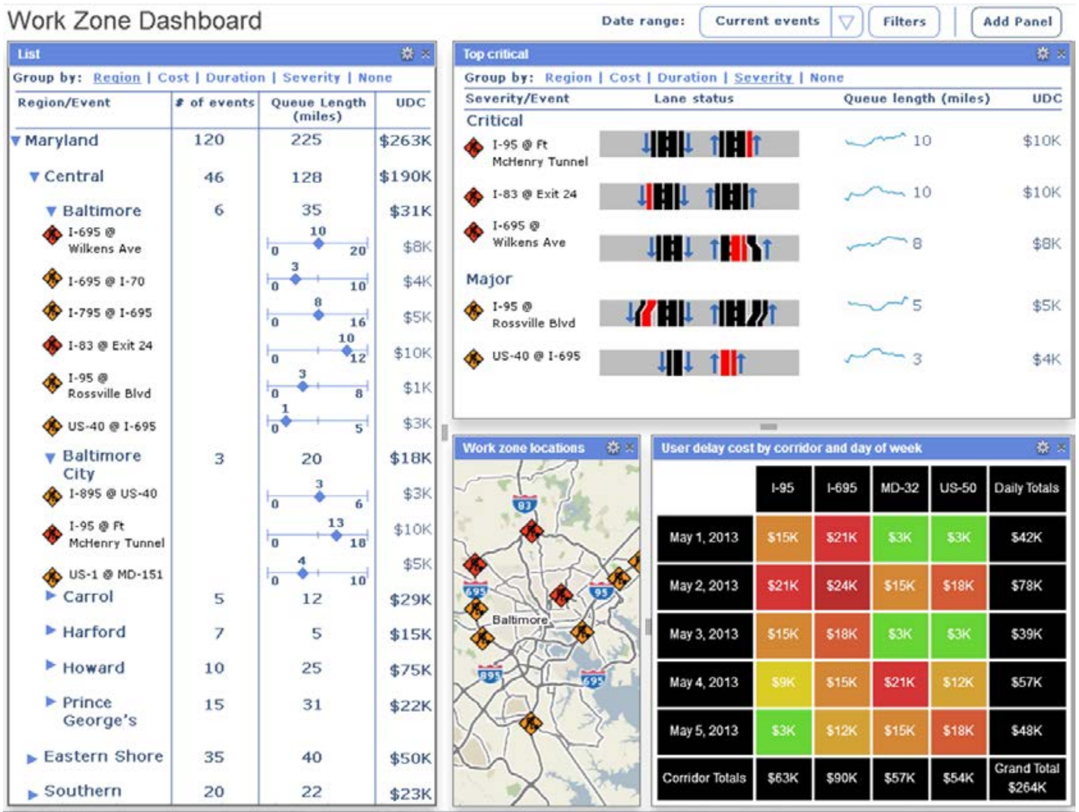

Figure 5. Prototype Work Zone Performance Measure Application (Area-wide Summary Dashboard)

Source: Slide 11 of the UMD CATT WZ Probe Data Presentation [5]

In this screen, the panel at the left lists the active work zones in the State and provides summary information on each. The top-right panel lists critical work zones. The bottom middle panel maps the work zone locations. The bottom right panel summarizes the total mobility performance of all the active work zones in the State.

The tool also includes other features that accommodate some of the suggestions made. The Filters button at the top right can help a user search through the work zones. The Add Panel button allows a user to customize the dashboard.

Selecting a specific work zone brings up a dashboard (see Figure 6) that provides more detailed information about the selected work zone.

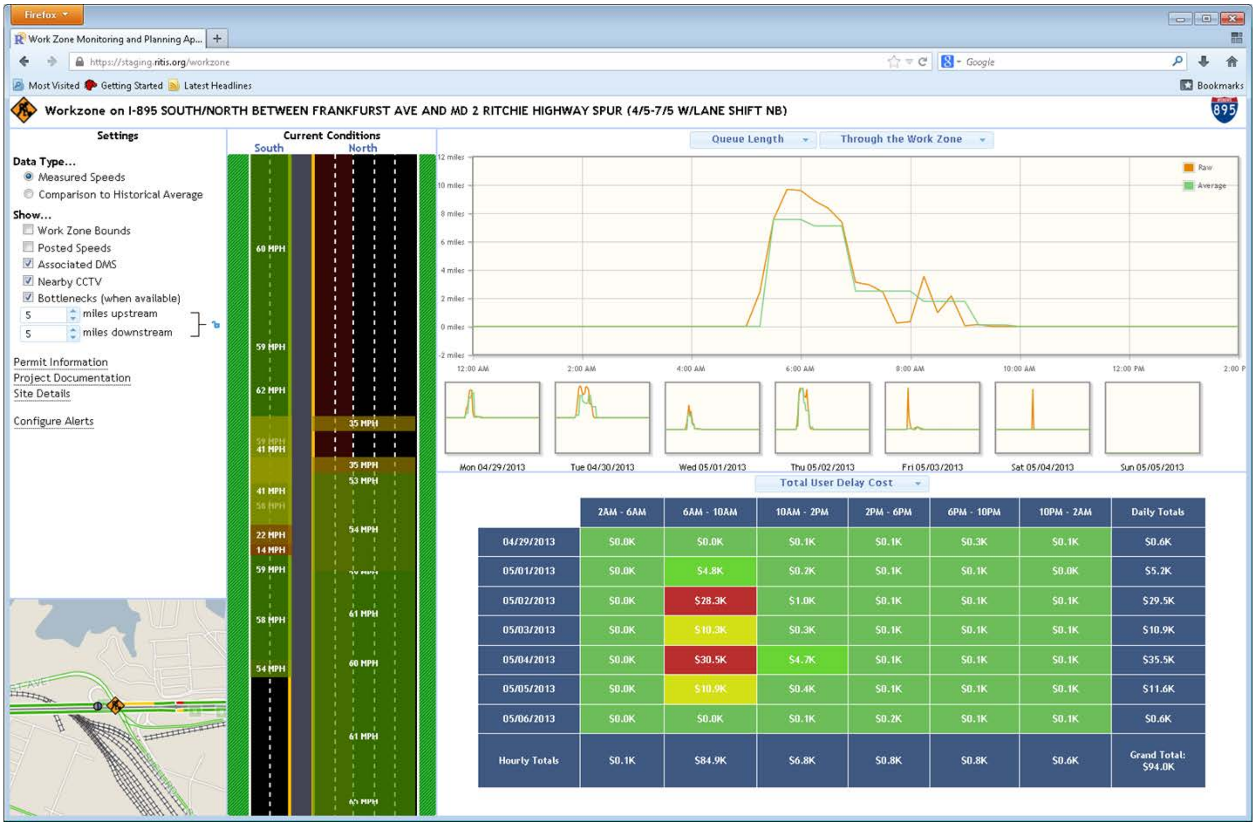

Figure 6. Prototype Work Zone Performance Measure Application (Project Level Dashboard)

Source: Slide 12 of the UMD CATT Work Zone Probe Data Presentation [5]

The panel at the left displays general information about the work zone, provides links to additional information, and provides options for configuring the information displayed in the other panels. The middle panel is a speed map that displays current work zone conditions. The top right panel displays a recent time history of a work zone performance measure. Drop-down boxes allow the user to select the performance measure to display. The panel at the bottom right summarizes the mobility impacts of the selected work zone.

The prototype WZPM application also includes a tool for creating customized alerts, as shown in Figure 7.

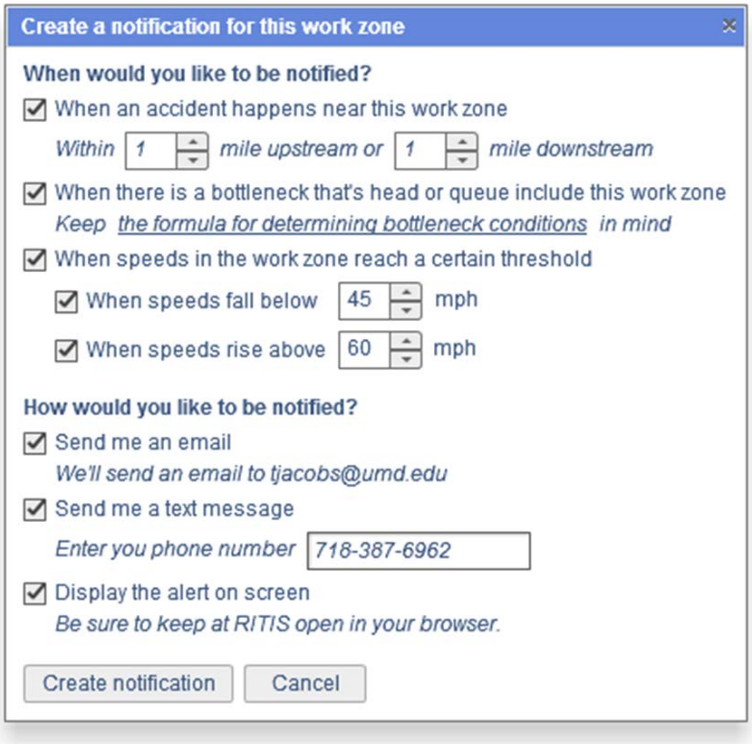

Figure 7. Prototype Work Zone Performance Measure Application (Alert Configuration Tool)

Source: Slide 13 of the UMD CATT Work Zone Probe Data Presentation [5]

This tool allows a user to customize whether they want to be alerted based on the present of an accident, a bottleneck, or if speeds go above or below a set amount. The user can choose one or more criteria for activating an alert (e.g., when an accident occurs, when a queue forms, when speeds cross specified thresholds) and one or more methods for distributing the alert (e.g., email, text message, on-screen notification).

3.1.7 Summary of Lessons Learned

The following list summarizes lessons learned related to the MDSHA work zone performance measures application developed by UMD CATT.

- The WZPM application can help comply with assessments of work zone impacts on mobility and safety that are required by the Final Rule on Work Zone Safety and Mobility. See Section 3.1.1.
- The WZPM application can be readily adopted by any State that participates in RITIS and has access to state-wide probe data. See Section 3.1.1.
- Currently available probe data is sufficient to support work zone performance measures. See Sections 3.1.2 and 3.1.4.
- There are challenges in using commercially available probe data for work zone performance measures related to the alignment of the TMC segment boundaries with the work zone boundaries. See Section 3.1.3.
- There are many potential uses of a work zone performance measures application, including helping oversee construction activities, to support traffic operations, to provide information to the public, to respond to complaints, to respond to a contractor request for an extension or schedule change, and to prepare project documentation and bid documents. See 3.1.5.

3.2 Other examples

In addition to the UMD/CATT example above, a number of other States have explored the use of probe data for work zone performance measures. Table 9 lists examples of such projects. Additional details on each of these projects are provided below the table.

Table 9. Examples of Projects Using Probe Data for Work Zone Performance Measures

State	Experience with Probe Data Work Zone Performance Measures
2009, Indiana	Used Bluetooth detectors for work zone travel time measurements to support a real-time travel time system for travelers. Used other Bluetooth detectors to log data for post processing.
2011, Virginia	Compared Bluetooth travel time estimates versus benchmark data. Used commercial probe data to assess work zone performance measures for 15 work zones.
2011, TTI	Conduced pilot tests on work zone performance measures that included some probe data and published the Work Zone Performance Measures Pilot Test report.
2011, Minnesota	Used commercial probe data to estimate work zone travel times for a work zone traveler information system on I-35.
2012, Texas	Deployed Bluetooth detectors to support travel time monitoring for an I-35 expansion project. These detectors were supplemented by other traffic monitoring technologies.
2012, Wisconsin	Researchers used Bluetooth detectors to monitor vehicle movements within several work zones in order to examine route choice.
2012, Maryland	Developed techniques for computing work zone performance measures from multiple data sources, including probe data. Details provided in the previous section.
2013, Ohio	Use historic travel time data from a commercial vendor to track mobility impacts due to the Hoople Interchange Reconstruction project on I-75 near Cincinnati.
2013, Utah	Obtained license for statewide historic travel time data from a commercial vendor and is exploring uses, including work zone performance measures.
2013, USDOT	Conducted a Work Zone Performance Management Peer Exchange in Atlanta, Georgia that included a significant focus on the use of probe data to support work zone performance measures.

More information on each of these examples related to work zone performance measures using probe data is provided below.

Indiana, 2009 [7]

In the summer of 2009, Indiana DOT resurfaced approximately 10 miles of I-65. Data collection was performed using a mix of semi-permanent and portable Bluetooth detectors. The semi-permanent detectors were deployed by retrofitting portable dynamic message signs with a Bluetooth antenna and provided near real-time data. The portable, standalone units were used for initial baseline data collection (before portable dynamic message signs were deployed to the work zone) and, periodically, on diversion routes. The portable units logged data for post-processing rather than providing data in near real-time.

Some of the lessons learned reported by Indiana DOT include:

- Retrofitting portable dynamic message signs with Bluetooth detectors was a cost-effective way to obtain work zone travel time measurements.
- The availability of work zone travel time measurements provided quantitative data that supported evaluation of alternative work zone traffic management techniques.
- The work zone travel time measurements could be used to support performance based contracting methods, such as specifying maximum delay times and including rewards and penalties based on observed delay times.
- The use of portable detectors on diversion routes allowed Indiana DOT to assess and improve the effectiveness of their work zone traveler information. One improvement was the use of dynamic message signs to display information about targeted alternate routes. Prior to implementing this approach, real-time delay information was displayed and few probe vehicles diverted. After specifying diversion routes on the signage, more than 30 percent of probe vehicles diverted.

Virginia, 2011

The Virginia Department of Transportation acquired probe vehicle based travel time data for 2010 from a commercial vendor. Fontaine and Edwards [8] used this data to calculate travel time reliability measures at 15 work zone locations based on monthly average travel times.

Some lessons learned include:

- The use of average travel time over a month instead of day-specific travel time smoothed out the hourly and daily fluctuations in travel time and may have reduced the effectiveness of the measurements.
- The TMC segments for which travel times were available do not necessarily line up with the work zone. Therefore, the measured travel time at the work zone location can be influenced by the travel time at non-work zone locations, which results in lower variability in travel time reliability measures.
- The probe data used relied primarily on data from commercial vehicles. The data quality appeared to sometimes suffer at night and on arterials when commercial vehicle traffic was light.
- The vendor appeared to use both real-time and historical data to produce their traffic condition data. Full road closures could result in an inaccurate picture of a work zone area if the vendor was unaware of the closure because the system seemed to default to historical observations when no real-time data was available.

Texas Transportation Institute, 2011 [9]

The Texas Transportation Institute conducted a study to validate work zone performance measures. The study considers exposure (volume through the work zone and vehicle-miles-traveled through the work zone), queuing, delay, travel time reliability, and safety measures in their study. Third party probe vehicle data was used as part of the study; specifically, large truck speed data obtained from FHWA Office of Freight Management. They monitored the following five work zone locations:

- I – 95, Lumberton, North Carolina
- I – 95, Philadelphia, Pennsylvania
- I – 405, Seattle, Washington

- I – 15/US95 Design-Build Project, Las Vegas, Nevada
- I – 15 Express Lane Project, Las Vegas, Nevada

This report identifies probe based methods as appropriate for collecting work zone travel time data and describes methods for computing performance measures from various data sources. The study included the use of truck transponder data that was used as a source of speed data for each of the work zones considered in the report. Because of the limited amount of truck transponder data available during this study, there were no specific lessons learned related to the usage of this type of data. They did note challenges related to differences between the end points of the work zone and the end points for the segments for which speed values were reported.

Minnesota, 2011 [10]

Minnesota DOT conducted a trial using commercial probe data to assess the accuracy of using commercial probe data for arterial travel times. The project also included the use of commercial probe data for real-time monitoring of travel times through rural work zones on I-35 between Minneapolis and Duluth. These travel times were converted to travel delays, which were used on variable message boards to inform travelers of delays. The resulting travel delay system was used for several months, but was then terminated because of concerns about the accuracy of the travel time data on Sundays.

Overall traffic on Sundays was heavy because of significant tourist / vacation travel to Northern Minnesota, so there was potential for work zone congestion on Sundays. However, the primary source of probe data for the vendor providing data for this project was from commercial vehicles and commercial vehicle traffic was light on Sundays. Having few probe observations available during times when congestion occurred resulted in inaccurate travel time data on Sundays.

The lessons learned from this project include:

- Probe data systems that rely on commercial vehicle traffic can be less accurate during times when commercial vehicle traffic is light. This can be particularly problematic if there are times when commercial vehicle traffic is light and overall traffic is heavy.

Wisconsin, 2012

Wisconsin DOT supported work zone diversion studies at two rural and two urban work zone sites. Bluetooth detectors were deployed in pairs, triples, and quadruples to help identify changes in route choice that occurred with lane closures. The project did demonstrate the viability of using Bluetooth detectors to collect route choice data. Several limitations were noted:

- The overall detection rate was low – from 0.3 percent to 5.7 percent at one site. This limits the number of route choice observations produced by the system. Presumably, these numbers will increase as Bluetooth devices become more common on vehicles.
- Not all vehicles with a Bluetooth system on board are detected by the roadside Bluetooth detectors. This reduces the effectiveness of tracking vehicles past multiple detectors – the more detectors that must be related, the lower the effectiveness. For example, if only 50 percent of vehicles with Bluetooth devices are detected, then only 25 percent of vehicles detected at the first detector of a sequence of three detectors would be detected at each of the subsequent detectors to produce a valid triple of observations.

Maryland, 2012

This is the case study describe in detail in Section 3.1.

Texas, 2012

Texas DOT announced plans to use a traffic monitoring system that integrates data from Bluetooth detectors and radar systems to monitor traffic on a 96-mile stretch of I-35 that is scheduled for 17 construction projects between 2013 and 2017. Portable solar-powered Bluetooth readers are used to collect data and are repositioned along the route as work progresses. The project is still in operation and lessons learned from the system are not yet available.

<u>Ohio, 2013</u>

Ohio DOT has a contract with a commercial probe data vendor for access to historical travel time data. The available historical data goes back to 2011 and data for the previous month becomes available at the end of each month. One of the applications for that data was production of mobility charts to track mobility impacts of the Hoople Interchange Reconstruction project on I-75 near Cincinnati. These charts compare the cumulative hours of reduced speeds through the work zone with historical values. An example is shown in Figure 8.

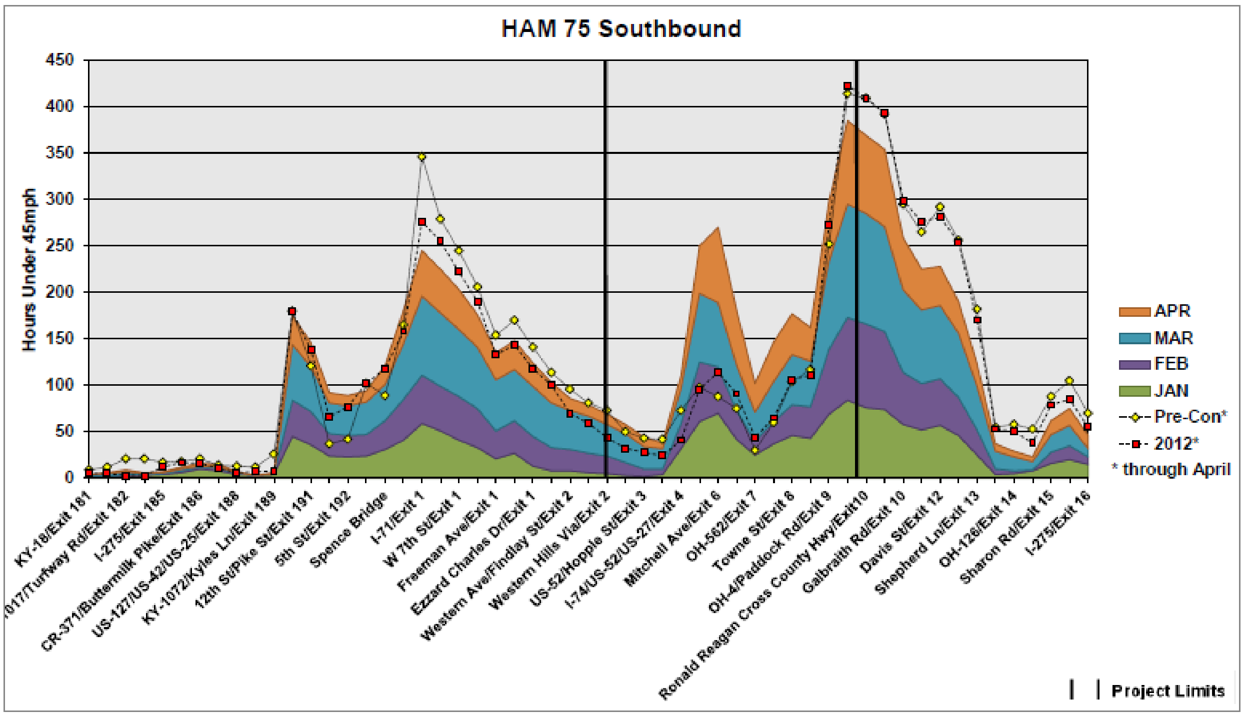

Figure 8. Ohio 45 mph Mobility Chart for the Hoople Interchange Reconstruction Work Zone

Source: Slide 5 of the Ohio DOT Mobility Charts presentation. [11]

In this example, the stacked line charts indicate the cumulative number of hours during which vehicle average speeds were below 45 mph for each month. The dotted lines represent the cumulative hours for the pre-construction years of 2011 and 2012. The vertical black bars represent the extent of the work zone. Note that the number of hours of reduced speed upstream and downstream of the work zone are similar to the historical values, while reduced speeds are much more prevalent within the work zone between Exit 4 and Exit 9 and, to a lesser extent, between Exit 1 and Exit 4. At Exit 6 (Mitchell Ave), the number of hours of reduced speed increased from about 100 hours in 2001 and 2012 to more than 250 hours in 2013.

Figure 9 shows a similar chart, but is for speeds reduced below 25 mph (i.e., for more severe mobility impacts). This chart shows a similar mobility impacts in and upstream of the work zone. Note that the upstream impacts extending back to Exit 1 give an indication of the queuing that formed upstream of the work zone.

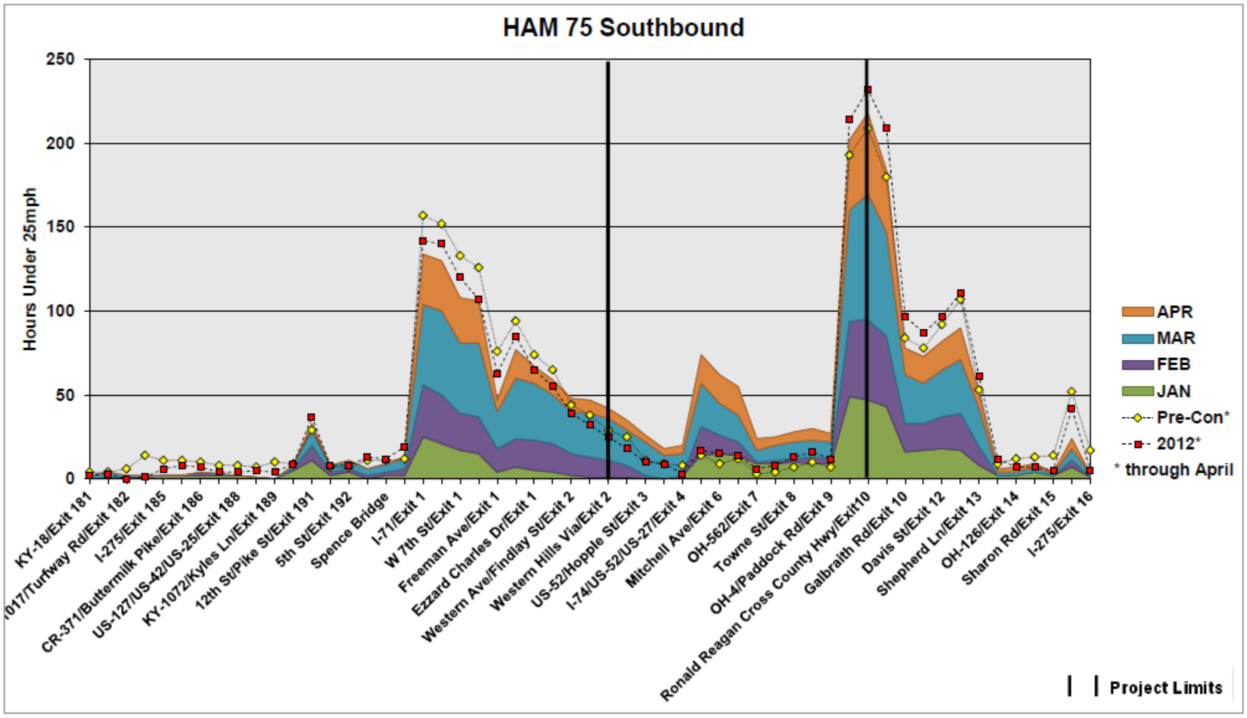

Figure 9. Ohio 25 mph Mobility Chart for the Hoople Interchange Reconstruction Work Zone

Source: Slide 6 of the Ohio DOT Mobility Charts presentation. [11]

Utah, 2013

In the summer of 2013, Utah DOT purchased a license to receive and use historical probe data from a third party vendor. The data is provided monthly for the preceding month and includes travel time information for arterials throughout the State. At the time of this report, UDOT had only just begun evaluating the data and how it could best be used. They did indicate that one usage they were considering was work zone performance measures.

USDOT, 2013[3]

FHWA hosted a Work Zone Performance Management Peer Exchange in May 2013 where the purpose was to discuss work zone performance management and how best to quantify such work zone impacts. The meeting objective was to examine the status of performance management and measurement by industry leaders. This meeting facilitated necessary dialog between different states so that participants could learn from one another. Common challenges were also raised among the group, and several states DOTs reported on recent uses of probe data for work zone performance measure, including some of these described in the previous case studies. The following paragraphs describe some additional insights that were revealed during this peer exchange.

The cost of probe data is cheaper than installing detection infrastructure. VDOT gets a discount on real time data due to their membership in the I-95 Corridor Coalition; states in similar organizations may be able to receive similar discounts. Massachusetts tried to approach GPS companies to see if they would be willing to update their information when a work zone is present; they were not interested.

[3] This information was obtained from a summary written on the Work Zone Performance Management Peer Exchange, which was completed by FHWA.

Bluetooth technology seems to be emerging in many states' practices. Agencies are using Bluetooth to determine travel times along segments, as well as segment speeds. They are using it to help to determine route choices as well. Wisconsin DOT ensures the accuracy of their variable message signs (VMS) by comparing speed data obtained from loops to Bluetooth data. Some deterrents from using Bluetooth data are that it is more like a 'cloud' than a 'point', and a signal can be detected more than once near a single Bluetooth detector device. Signals can also be interrupted by structures and buildings. The speed data obtained by Bluetooth devices applies to a segment, not a specific point. In Utah, agencies have learned that Bluetooth receivers can be programmed to collect either the first or last signal detection to avoid multiple counts of a single vehicle. In Virginia, they have seen a data trend that favors slower speeds, which is due to the fact that slower moving vehicles have a higher probability of being detected by a Bluetooth receiver.

At least one state (Utah) has experimented with using Bluetooth data to monitor performance for awarding performance incentives to contractors. Utah DOT conducted a test application of Bluetooth to determine whether managing contractor performance in this manner was feasible, as well as testing the validity of Bluetooth data. The incentives were based on anticipated road user costs. The project began with one week of Bluetooth data collection prior to the start of construction to set a baseline. Work zone scenarios were developed, and acceptable delay thresholds were chosen. Various warning messages could be displayed by contractors to aid them in meeting the delay thresholds. It was emphasized that agencies need to help contractors understand that Bluetooth (and other real time) data is there to help them, not to penalize them.

A report on the results of this peer exchange is scheduled for completion in September 2013. When completed, information about the report will be posted to the Work Zone Mobility and Safety Program website at http://ops.fhwa.dot.gov/wz.

References

1. Travel Time Data Collection Handbook. (1998). FHWA report.
2. Federal Highway Administration (FHWA), Work Zone Mobility and Safety Program, Traffic Analysis Tools Volume IX: Work Zone Modeling and Simulation: A Guide for Analysts, July 2009. http://www.ops.fhwa.dot.gov/wz/traffic_analysis/tatv9_wz/sec2.htm#content
3. Federal Highway Administration (FHWA), Private Sector Data for Performance Management: Final Report, July 2011. http://ops.fhwa.dot.gov/publications/fhwahop11029/ch3.htm
4. Work Zone Performance Measure Definitions, Formulas, Recommendations, and Sample Calculations (draft), produced by the Center for Advanced Transportation Technology (CATT) Lab at the University of Maryland, April 2013.
5. Jacobs, Tom. WZ Probe Data – MD SHA. Presentation at the Work Zone Performance Measurement Peer Exchange, May 8, 2013.
6. Ullman, Gerald, Timothy Lomax and Tracy Scriba. A Primer on Work Zone Safety and Mobility Performance Measurement. FHWA Report Number FHWA-HOP-11-033.
7. Haseman, Ross, and Darcy Bulluck. Real Time Measurement of Work Zone Travel Time Delay and Evaluation Metrics Using Bluetooth Probe Tracking, TRB Paper 10-1442, November 2009.
8. Edwards, M.B. and M.D. Fontaine. Investigation of Work Zone Travel Time Reliability Using Private Sector Data, Proceedings of the 91th TRB Annual Meeting, Transportation Research Board of the National Academies, Washington, D.C., 2012. http://www.workzonesafety.org/research/record/11815
9. Federal Highway Administration (FHWA), Work Zone Performance Measures Pilot Test, April, 2011 http://www.ops.fhwa.dot.gov/wz/resources/publications/fhwahop11022/fhwahop11022.pdf
10. Arterial Real-Time Traveler Information (Commercial Probe Data), MnDOT No. 97544, September 2012. http://www.dot.state.mn.us/guidestar/2012/arterial-real-time-traveler-probe/pdf/FinalReport103012.pdf
11. Stargell, Reynaldo. Ohio DOT Mobility Charts, Presentation at the Work Zone Performance Management Peer Exchange, May 8, 2013.

Appendix A: Future of Probe Data

Mobile Data Generation

Technology has become ubiquitous with the advent of personal devices such as smart phones and mobile tablets (“iPod” like devices). Equally important is the advent of the “app” stores where specialized software applications can be quickly added to these personal devices enabling almost any function imaginable. So it would not be difficult to create and deploy an application for these devices to generate the mobile data desired by the transportation community. In fact, there is precedent with the tracking cookies used by web sites to track visitors on the internet.

Connected Vehicle systems are also a potential future source of probe data. The concept for Connected Vehicles calls for each vehicle to be equipped with GPS tracking and a Dedicated Short Range Communication (DSRC) system to provide wireless communication between vehicles and between a vehicle and roadside infrastructure. While the primary focus of early Connected Vehicle research has been on improving vehicle safety, there have also been several pilot projects that have demonstrated the potential for these systems to produce probe data.

Mobile Data Collection

Collecting mobile data from these devices, both personal and embedded, while technically feasible, may have more to do with economic incentives and associated business models. The communications protocols such as Wi-Fi or Bluetooth communications are already present in these technology devices so localized data transfer would not be an issue. The mobile data “app” would provide the user the ability to authorize the data transfer to an entity in exchange for economic consideration. A real time mobile data model would require the use of existing commercial communications such as cellular or broadband. The individual would bear the upfront cost through their existing service plans. However, depending on who the data aggregator is, an economic incentive may also be viable to offset the consumer data transmission costs. There are examples of mobile data being collected today through standalone GPS device providers such as TomTom.

Specific Issues that Will Shape Future Mobile Data

Existing mobile devices, particularly the smartphone market, has connected over 82 million users in the United States to the internet. The overwhelming majority of these devices include one or more GPS services that support real-time location information between the device and the service provider. This penetration rate of nearly 25% provides the capability to have robust traffic information for most of the country. For example, mobile users of Google Maps with the GPS enabled currently feed anonymous data back to Google that provides a speed profile. Google combines that information with other users to produce the traffic layers on their maps.

Effectively, every GPS enabled device including handheld navigation systems, and vehicles themselves through services such as GM’s On-Star and Ford’s SYNC can all collect detailed speed and location data to support a variety of mobility applications.

Looking beyond standard GPS utilities, the Bluetooth travel time collection market has proven to be a very cost effective source of mobile data for DOTs in evaluating congestion and travel characteristics, often with relative small penetration rates, sometimes less than 5 percent.

Insurance companies like Progressive have implemented Pay As You Drive (PAYD) insurance plans with associated measuring devices to allow users to pay based on per mile activity.

There are two key constraints to accessing mobile data sets.

1. Privacy – Despite the fact that people are no longer truly moving anonymously through the streets, in stores, and at home.
2. Private Sector Market Data – Although users of mobile devices are often willing to opt-in and share their private data, the collectors often have a competitive reason for not sharing details that reveal information about the numbers of customers, location densities of the customer base, and on/off status type of data.

Just as importantly the true utility and applicability of the information can be cloudy with the ability to effectively characterize the answers to the following questions.

- Can the frequency of collected location, speed and other movement data be effectively defined per data source?
- Can any penetration rate or volume data be gathered from the sources?
- What is the native accuracy of the data collected?
- Is the collected data available in sufficient intervals to support desired applications?
- What is the cost move that data and who will bear that cost?
- What is the cost to aggregate and integrate the data into safety and mobility applications?

Independent of the technological considerations, the willingness of the users and the simplicity with which they share their information, be it on a smart phone, at a point-of-sale handoff at the gas station, intersection, or store via a debit/credit transaction, or download from the vehicle, will depend on the handoff being unobtrusive and with some value provided back to the users. That value could be in many forms ranging from cash back payments to discounted services and goods to free applications or services.

While the connected vehicle initiatives will bring a level of coordination and standardization to the data collection process for very specific transportation analysis data, the reality is the private sector market place will move forward without standards, particularly where the value in sharing the information may support more private business strategic analysis and marketing uses. For example, if a company can more effectively market goods and services, by better targeting consumers, then those companies may be willing to pay the bills that support the collection of location information. For example, with the prevalence of electronic billboards, particularly in urban environments, the near real-time understanding of the density of potential customers and even potentially demographic information may provide those advertisers with a better return in terms of where, when and how to utilize the billboards, and potentially how to modify and target other marketing methods.

Looking at an even more anonymous method of obtaining traffic information, the potential for high resolution satellite imagery and high resolution video analytics at least has the potential to serve as a massive CCTV network without requiring any user buy-in. For example, scaling up the powers of video analytics systems such as those provided by Citilog, Abacus, and other video technologies may be feasible. The ability to pay for that type of deployment is unclear.

Mobile Data Summary

In the final analysis, it would be difficult for any one company to have the core competencies for providing an end-to-end solution with sufficient market share to generate the volume and geographic footprint needed. While the technology has been present, four key success factors are:

- Reaching the mass market with minimal infrastructure, time to deploy and cost
- Applying the technology in a new or different way
- Creating new and beneficial business model(s)
- Strategic partnership(s) combining disparate core competencies.

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