GUIDE TO BENCHMARKING OPERATIONS PERFORMANCE MEASURES

PRELIMINARY DRAFT
FINAL REPORT

Prepared for
NCHRP
Transportation Research Board
of
The National Academies

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES
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Philip J. Tarnoff
Stanley E. Young
Joshua Crunkleton
Nezamuddin Nezamuddin
University of Maryland
Center for Advanced Transportation Technology
College Park, Maryland
January 2008
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University of Maryland
Center for Advanced Transportation Technology
College Park, Maryland
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- City of Overland Park, Kansas
- City of Vancouver, Washington
- Colorado DOT
- Florida DOT
- Federal Highway Administration
- Georgia Regional Transportation Authority
- Inrix Inc.
- International City/County Management Association (ICMA)
- Institute of Transportation Engineers (ITE)
- Maricopa Association of Government (MAG)
- Maryland State Highway Administration
- Metroplan Orlando
- Missouri DOT, Kansas City Scout
- North Jersey Transportation Planning Authority
- Regional Transportation Commission of Southern Nevada
- Texas A&M
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ABSTRACT

In 2005, the National Transportation Operations Coalition (NTOC) identified and prepared high level definitions for a set of twelve key operations performance measures useful for the evaluation of transportation mobility and adaptable to national applications. This project furthered those efforts by refining the initial measures, testing the data collection and data compilation procedures through a series of pilot tests, and developing implementation guidelines for these measures. Input from senior transportation professionals across the United States and the results of a pilot testing initiative conducted during 2007 served as the basis for developing these products. During the pilot test initiative, state DOTs, cities, and MPOs contributed sample data and shared their experience implementing various measures. The information gathered included technical challenges, applications, reporting mechanisms, and implementation costs. The twelve NTOC performance measures include:

- Customer Satisfaction
- Extent of Congestion – Spatial
- Extent of Congestion – Temporal
- Incident Duration
- Non-Recurring Delay
- Recurring Delay
- Speed
- Throughput – Person
- Throughput – Vehicle
- Travel Time – Facility
- Travel Time – Reliability
- Travel Time – Trip

Revised performance measure definitions and implementation guidelines are the primary deliverables. These products are intended for use by agencies implementing such measures in order to establish their utility for both internal and external applications.
EXECUTIVE SUMMARY

In 2005, the National Transportation Operations Coalition (NTOC) identified and defined twelve key operations performance measures of national significance. This project furthered that effort by further refining their definitions, evaluating the issues associated with their use, and developing implementation guidelines. Similar to the original NTOC initiative, this work was performed cooperatively with state DOTs, MPOs, local government agencies, academia, and industry. Such organizations collaborated with the University of Maryland (UMD) to refine the measures, and contributed data and lessons-learned during pilot testing which served as a primary source to develop implementation guidelines. An initial project workshop, ongoing email exchanges, and conference calls enabled the exchange of information, and a pilot testing program conducted during 2007 provided the opportunity for organizations to share their experience implementing the various measures within their agencies.

A workshop of transportation professionals hosted in February of 2007 in Washington DC provided a forum to review the initial NTOC work, clarify the measures as needed, and lay the groundwork for pilot testing during 2007. The twelve measures, as refined at the workshop, include:

- **Customer Satisfaction**: A qualitative measure of customers’ opinions related to the roadway management and operations services provided in a specified region.
- **Extent of Congestion – Spatial**: Miles of roadway within a predefined area and time period for which average travel times are 30% longer than unconstrained travel times.
- **Extent of Congestion – Temporal**: The time duration during which more than 20% of the roadway sections in a predefined area are congested as defined by the “Extent of Congestion – Spatial” performance measure.
- **Incident Duration**: The time elapsed from the notification of an incident until all evidence of the incident has been removed from the incident scene.
- **Non-Recurring Delay**: Vehicle delays in excess of recurring delay for the current time-of-day, day-of-week, and day-type.
- **Recurring Delay**: Vehicle delays that are repeatable for the current time-of-day, day-of-week, and day-type.
- **Speed**: The average speed of vehicles measured in a single lane, for a single direction of flow, at a specific location on a roadway.
- **Throughput – Person**: Number of persons including vehicle occupants, pedestrians, and bicyclists traversing a roadway section in one direction per unit time. May also be the number of persons traversing a screen line in one direction per unit time.
- **Throughput – Vehicle**: Number of vehicles traversing a roadway section in one direction per unit time. May also be the number of vehicles traversing a screen line in one direction per unit time.
Travel Time – Facility

The average time required to traverse a section of roadway or other facility in a single direction.

Travel Time – Reliability

The Buffer Time is the additional time that must be added to a trip to ensure that travelers will arrive at their destination at, or before, the intended time 95% of the time.

Travel Time – Trip

The average time required to travel from an origin to a destination on a trip that might include multiple modes of travel.

During 2007, over a dozen state DOTs, cities, and MPOs contributed sample data, reports, and lessons learned from implementing the performance measures within their organizations. The level of experience varied considerably among the participants. Some organizations had well-established data collection, compilation, and reporting programs. Others were at various stages of implementing data collection programs, and were experimenting with the most effective means to compile and report the various measures. The bulk of this report is the compilation, summary and conclusions drawn from material contributed during the pilot tests. This information served to further refine the performance measure definitions and to develop implementation guidelines specific to each measure. The reader is referred to the appendices for the refined definitions and implementation guidelines. A brief summary of the findings and overview of the guidance specific to each performance measure follows.

Customer Satisfaction and Incident Duration performance measures are widely practiced and well established as evidenced from the pilot test results. The data collection and reporting processes for these measures are mature and well understood. The implementation guide summarizes existing best-practice, identifies critical issues, characterizes costs, and references additional resources available to assist organizations implementing such measures.

The remaining ten performance measures, referred to collectively as Traffic Flow Measures, are all derived from measurements of speed, travel-time and/or volume. Pilot test data indicate that experience implementing Traffic Flow Measures is more readily available for freeways than for signalized arterials. Several positive case studies for freeway implementation are available, such as the Washington DOT, Georgia Regional Transportation Authority and Maricopa Association of Governments, to name a few. For freeway systems, the primary implementation challenge is the development of an effective data collection system given the myriad of methods and technologies of varying cost and accuracy currently available. New business models and technologies are emerging to procure speed, travel time, and volume data. These new systems promise to reduce cost, minimize maintenance, and minimize intrusion into the roadway while providing timely and accurate data. As a result, organizations are faced with a matrix of choices between old and new technologies, each with differing accuracy, quality control issues, and cost implications. Assistance with navigating this matrix of methods and technology is the primary focus of the corresponding implementation guidelines for Traffic Flow Measures.

Application of Traffic Flow Measures on arterials is complicated by another factor. The quality of traffic flow on arterials is governed primarily by delay at signal controlled intersections. For this reason spot-speed measurements are relatively ineffective as an indicator of flow performance. Data collection methods that directly measure travel time, such as floating cars
and vehicle probes, must be employed. As such, examples of traffic flow performance measures on arterials are much less prevalent. Due to the expense associated with traditional floating car methods, data collection on arterials has, until recently, been limited to yearly sampling as exhibited by Colorado DOT and the city of Overland Park, KS submittals. Newer vehicle probe technologies, such as the automated toll-tag matching system employed on the arterials in the Orlando, Florida, are emerging to provide continuous data streams and enabling additional performance measure applications. The concept of ‘unconstrained travel time’ based on off-peak flow measurements is also not applicable to arterials. Signal timing typically varies throughout the day to balance the throughput demand (during rush hours) with side street and business access (typically during non-rush hour periods). As a result, off-peak travel time can and frequently does exceed that of the peak period due to signal timing. As a result an alternative method to estimate ‘unconstrained travel time’ was developed for arterials.

Of the various Traffic Flow Measures, travel time is the primary and dominant measure in use. Its ease of application and inherent understanding by the traveling public provides the greatest benefit for application and reporting purposes. The next tier of measures includes speed, throughput measures, reliability, and recurring delay. Although less prevalent than travel time, the implementations of these measures were consistent, reporting mechanisms mature, and applications clearly defined. In contrast, extent of congestion measures, and non-recurring delay were not widely reported, if at all. At least three organizations experimentally implemented the NTOC-defined extent of congestion measures as part of the pilot test, but no established performance measures system using the NTOC definition was identified. Several organizations attempted to quantify the time and spatial extents of congestion based either on travel-time or throughput data, but no universal method has emerged around which to standardize. It is unclear at this time whether the NTOC-defined extents of congestion measures provide the required functionality. No examples of non-recurring delay were submitted as part of the pilot tests, although some data submitted for incident duration could be construed as such. Although non-recurring delay is a clear concept, direct measures have not emerged as an effective performance measure. Therefore, the project concludes that non-recurring delay should be omitted from the list of core operations performance measures.

The NTOC measures, as refined in this study, and the associated implementation guidelines, will assist organizations seeking to develop effective operations performance measures programs based on nationally acknowledged data collection methods, compilation procedures, and reporting mechanisms. As conveyed in the results of this study, multiple positive case studies exist for the majority of the NTOC measures from which organizations can acquire templates and lessons-learned in order to affect their own efficient implementation. Moving forward, as additional experience is gained with emerging traffic flow technologies and methods, the material in the guidelines should be augmented with the knowledge from the most recent deployments. Likewise, knowledge and methods to effectively characterize and communicate extent of congestion measures will continue to develop and should serve to augment the guidance conveyed herein.
CHAPTER 1 : BACKGROUND

In 2005, the National Transportation Operations Coalition (NTOC) established a performance measurement action team to identify and prepare high level definitions of measures useful for the evaluation of transportation mobility. The activities of the team were coordinated and documented by the International City/County Management Association (ICMA) and the University of Maryland. The team was made up of senior transportation professionals from across the United States, with balanced representation from federal, state, and local transportation agencies, Metropolitan Planning Organizations (MPOs) and their associated professional societies. The team identified a common set of measures determined to be appropriate for adaptation to national applications. A final report [1] was prepared that documented the results of this activity and included initial definitions for each of the twelve measures that were selected. The twelve original NTOC measures included:

- Customer Satisfaction
- Extent of Congestion – Spatial
- Extent of Congestion – Temporal
- Incident Duration
- Non-Recurring Delay
- Recurring Delay
- Speed
- Throughput – Person
- Throughput – Vehicle
- Travel Time – Link
- Travel Time – Reliability
- Travel Time – Trip

The NCHRP 20-7 project built upon and advanced the NTOC initiative, using a similar approach that engaged transportation officials to:

- Define more precisely the selected measures in terms of sample sizes, measurement techniques, and measurement conditions
- Test the data collection, processing, reporting, and verification processes needed to implement performance management.
- Document the experience of local agencies with the use of these measures in order to establish their utility and cost for both internal and external applications
CHAPTER 2 : RESEARCH APPROACH AND PROCESS

This research was performed cooperatively with state department of transportations (DOTs), metropolitan planning organizations (MPOs), and local government agencies. Project participants helped refine the measures and develop implementation guides through collaboration and submitting pilot test results.

This research was accomplished through the following tasks:

Task 1. Solicit and confirm project participants

The key to a successful project was the involvement of project participants who helped focus the effort on the missions, goals, and outcomes of performance management as it applies to transportation operations. These participants helped to refine the performance measure definitions. Volunteer transportation organizations were sought to collect and share data as part of the pilot testing phase of the project. Participating associations were requested to assist in the ongoing outreach for this project through periodic articles, sessions at conferences, or through other distributions to members, as appropriate.

Task 2. Convene and facilitate a two-day project workshop

A two-day workshop was hosted at the project outset in early 2007 to solicit input from project participants. The agenda for the workshop was to:

- Establish a consistent, standard set of performance measure definitions.
- Advise on data collection procedures, sample size and processing requirements for each item of data to be collected for each measure.
- Determine if data is readily available or can be collected within a reasonable amount of effort by transportation management and operations staff.
- Advise on a survey instrument and template to collect the data.
- Advise on potential pilot test locations.

Task 3. Establish minimum sample sizes for data collection

Characterizing adequate data sample sizes was identified as a key aspect to the successful implementation of operation performance measures. Existing guidelines for some measures were either incomplete or based on simulation results with no field verification. Data collection and sample size guidelines were established based on literature review, data analysis, and the experience of organizations pilot testing many of the measures.

Task 4. Data collection, reporting, and cleaning

The performance measures and associated guidelines were pilot tested by volunteer organizations during 2007. Guidelines and data collection templates developed by the University of Maryland provided a structure to process and submit data, results, and estimated costs. The University of Maryland reviewed the data and results submitted by participants for
consistency and to ensure that they were within the reasonable range of such data items. Analysis of the data submitted during pilot testing helped refine the performance measures, identify critical issues, and highlight any needs for further research or analysis.

**Task 5. Collect feedback and conduct evaluation**

This task provided the mechanism to gain feedback from the project participants. To facilitate feedback and evaluate the project, participants were asked to provide summary remarks along with their data submittals. They were also given the opportunity to participate in conference calls prior to and after data collection. The remarks and focus of discussion were to include such topics as the adequacy and definition of the measures, data collection and reporting process, effectiveness of the performance measures in communicating performance objectives with its constituency, and the ability of the participants to use and sustain these processes into the future.

**Task 6. Produce and disseminate final report and guidelines**

This report summarizes the results and findings of each task. A stand-alone guidelines document was prepared to be used as a handbook by agencies wishing to implement operations performance measures. The handbook was submitted to both the project participants as well as the NCHRP panel.
CHAPTER 3: FINDINGS AND APPLICATIONS

The success of the project was contingent upon the participation of organizations throughout. Organizations that contributed either through attendance in the workshop or support of the pilot testing activities included:

**Professional Organizations / Coalitions / Government**
- Association of Metropolitan Planning Organizations (AMPO)
- Federal Highway Administration (FHWA)
- Institute of Transportation Engineers (ITE)
- International City/County Management Association (ICMA)
- I95 Corridor Coalition
- National Transportation Operations Coalition (NTOC)
- National Associations Working Group (NAWG)
- Transportation Research Board (TRB)
- Volpe National Transportation Systems Center

**State and Local Transportation Agencies & MPOs**
- Baltimore Metropolitan Council
- City of Overland Park, Kansas
- City of Vancouver, Washington
- Florida DOT
- Georgia Regional Transportation Authority
- Maricopa Association of Government (MAG)
- Maryland State Highway Administration
- MetroPlan Orlando
- Missouri DOT, Kansas City SCOUT Traffic Management Center
- North Jersey Transportation Planning Authority
- Southern Nevada Regional Transportation Commission (RTC)
- Utah Department of Transportation
- Virginia DOT
- Wasatch Front Regional Council
- Washington DOT

**Business, Industry, & Universities**
- Cambridge Systematics Inc.
- Inrix Inc.
- Texas A&M University
- Traffic.com
- University of Maryland, Center for Advanced Transportation Technology

The results of the various aspects of the project are presented below. The Pilot Test results are summarized in section 4.
3.1 Participants Workshop

A two-day participant workshop was convened on February 27-28, 2007 at the National Academy of Sciences building in Washington DC. Eighteen people attended the two day workshop, with another four joining via teleconference. Representation included state DOTs, MPOs, industry, academia, and professional associations. The minutes from the meeting are included in Appendix C.

Using the NTOC results as a starting point, participants reviewed the twelve proposed measures at a high level to determine if any significant operations performance metrics were omitted. In-depth discussions of each performance measure accounted for the majority of the time and effort. The input from the workshop served to refine the twelve key performance measures and to shape and guide the subsequent pilot testing effort. Participants also identified likely geographic regions and their corresponding transportation authorities to assist in pilot testing.

The workshop resulted in several changes in the original NTOC definitions of the twelve key measures. The Customer Satisfaction measure was revised to a broader, more general definition with emphasis on process rather than sample content. Travel Time – Link was renamed to Travel Time – Facility to reflect applicability to any mode, but still be specific to a single facility. The workshop developed a more thorough definition of ‘Unconstrained Travel Time’ needed in the calculation of several of the traffic flow measures. The workshop revised Unconstrained Travel Time as follows.

Unconstrained Travel Time represents a reasonable estimate of travel time in the absence of congestion during good weather conditions. Two different methods of determining unconstrained travel time may optionally be used as the basis for the appropriate performance measures. The first method is preferred:

1. 85th percentile travel time (corresponding to the 85th percentile speed converted to an equivalent travel time) of traffic during off-peak periods.

2. Target travel time defined as the time it takes motorists to traverse a roadway section when they are traveling at speeds established by operations personnel as the desired speed for a given roadway under prevailing roadway and traffic conditions

Off-peak periods are defined as any time that traffic flow exhibits Level of Service C or better.

3.2 Refinement of Performance Measures Definitions

In addition to the revisions introduced as the result of the workshop, other numerous changes and refinements to the definitions occurred throughout the project as the result of pilot testing, literature review, analysis, and collaborative with transportation professionals. The definitions of the refined performance measures are provided in Appendix A. The refined definitions are the first of the two primary deliverables.
3.3 Performance Measures Accuracy Requirements

A broad array of sensor technology is available to collect data in support of traffic flow performance measures and various applications of those measures. The demand for traffic data to support congestion monitoring, incident detection and other ITS operations combined with traffic engineering and planning data needs are pushing agencies to find ways to consolidate and integrate data collection systems. Previously, traffic engineering, planning and operations would implement separate and independent data collection efforts to support specific applications such as signal actuation, long-range planning, or incident detection. An understanding of the data accuracy requirements of applications is required in order not only to select appropriate technology for each individual application, but also to consolidate data collection efforts so that an investment in one data collection system could serve multiple needs.

To this end, UMD developed a framework to characterize the accuracy required to support various applications of the performance measures as shown in Table 1. Table 1 depicts an accuracy range for each measure for four classes of applications: Traffic Engineering, Transportation Planning, and Operations applications of Traffic Management and Traveler Information. The acceptable accuracy ranges are based on input from project participants, pilot test results, analysis, and literature review, though the latter was scant. If the error in the performance measure is greater than that specified in the range, the application will be adversely affected. For example, 20% error is often cited as the maximum allowed error in travel time estimates for traveler information applications such as travel times on changeable message signs. If the error exceeds 20%, the public will quickly lose confidence in the information source, undermining the support and usefulness of the system. If the error in the performance measure is less than that specified in the range, it is still useful for the application, but the application does not benefit appreciably from the increased accuracy.

Note that in Table 1, Transportation Planning encompasses any type of planning or long-range monitoring activity. The year-to-year fluctuation in corridor travel times falls into this category. The grayed sections imply that the performance measure is not applicable to the intended application.
TABLE 1  Performance Measure Accuracy Requirements  [a. Getting to the Infostructure, A White Paper prepared by Phil Tarnoff, TRB Roadway INFOstructure Conference, August 21-24, 2002  - Possible INFOStructure Performance Requirements  b. Accuracy requirements of the I95 Vehicle Probe RFP, AAE is Average Absolute Error]

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Traffic Engineering</th>
<th>Transportation Planning</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer Satisfaction</td>
<td>5% - 10%</td>
<td>5% - 20%</td>
<td></td>
</tr>
<tr>
<td>Incident Duration</td>
<td></td>
<td></td>
<td>5% - 10%</td>
</tr>
<tr>
<td>Throughput - Vehicle</td>
<td>1% - 5%</td>
<td>2% - 10%</td>
<td>5% - 10%[a]</td>
</tr>
<tr>
<td>Throughput - Person</td>
<td>2% - 5%</td>
<td>5% - 10%</td>
<td>5% - 15%</td>
</tr>
<tr>
<td>Speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel Time - Facility</td>
<td>1% - 5%</td>
<td>2% - 10%</td>
<td>5% - 10%[a][b]</td>
</tr>
<tr>
<td>Travel Time - Trip</td>
<td></td>
<td></td>
<td>5% - 20%[a]</td>
</tr>
<tr>
<td>Travel Time - Reliability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recurring &amp; Non-Recurring Delay</td>
<td>5% - 10%</td>
<td>5% - 15%</td>
<td>5% - 10%</td>
</tr>
<tr>
<td>Extent of Congestion</td>
<td></td>
<td></td>
<td>10% - 20%</td>
</tr>
<tr>
<td>Spatial &amp; Temporal</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

3.4 Minimum Sample Size Analysis

Each NTOC performance measure is calculated from an amassed database of individual observations, be it speeds, volumes, travel time, survey responses, or times associated with incident response. Table 2 attempts to identify the critical issues involved in obtaining quality data for each of the performance measures. In many instances the primary issues that affect quality also directly impact cost. For example, as the complexity of the Customer Satisfaction survey increases, the cost to develop, conduct, and process the survey also escalates.

TABLE 2  Performance Measures Data Collection Issues

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Base Data / Record</th>
<th>Measurement Methods</th>
<th>Primary Issue/s</th>
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</thead>
<tbody>
<tr>
<td>Customer Satisfaction</td>
<td>Survey Response</td>
<td>Constituent Survey</td>
<td>Complexity of Survey</td>
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<tr>
<td>Incident Duration</td>
<td>Accident Record</td>
<td>Analysis of Accident Database</td>
<td>Data Definitions</td>
</tr>
<tr>
<td>Throughput - Vehicle</td>
<td>Vehicle Count</td>
<td>Spot Vehicle Counters</td>
<td>-</td>
</tr>
<tr>
<td>Throughput - Person</td>
<td>Person Count</td>
<td>Vehicle Occupancy Surveys</td>
<td>-</td>
</tr>
<tr>
<td>Speed</td>
<td>Speed Detection</td>
<td>Spot Speed Sensors</td>
<td>QCQA of Sensors</td>
</tr>
<tr>
<td>Travel Time - Facility</td>
<td>Estimate of Travel Time</td>
<td>Inference from Speed Sensors</td>
<td>QCQA of Sensors</td>
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<tr>
<td>Travel Time - Trip</td>
<td></td>
<td>Floating Car Methods</td>
<td>Density of Sensors</td>
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<td>Travel Time - Reliability</td>
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<td>Vehicle Probe Methods</td>
<td>Sensor Outages</td>
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<tr>
<td>Recurring Delay</td>
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<td></td>
<td>Conversion of Speed to Travel Time</td>
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<tr>
<td>Non-Recurring Delay</td>
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<td></td>
<td>Density of Probes</td>
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<tr>
<td>Extent of Congestion</td>
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</tr>
<tr>
<td>Spatial &amp; Temporal</td>
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</table>

10
Traffic flow performance measures (referring to all measures except customer satisfaction and incident duration) are all derived from speed, travel time, and/or volume data. The accuracy of traffic flow measures are ultimately dependent on the quality of the data collected in the field, which in turn is based on the accuracy of each individual measurement and the number of measurements made, also called the sample size. Sample size considerations are most critical whenever periodic data sampling is performed in lieu of deploying a system that continuously measures and logs traffic data.

Assuming that the error in any individual measurement is negligible, sample size requirements become a function only of the inherent variability of the traffic stream. As such, a fundamental understanding of the variance of speed, travel time, and volume of the traffic stream are essential to estimate minimum sample sizes for varying degrees of confidence and accuracy. To this end, UMD analyzed the underlying variability of these fundamental traffic parameters using data from pilot tests and other available archived sources. Specifically, the analysis measured the sample standard deviation of these parameters as functions of per lane hourly volume (vphpl). A full copy of the analysis is included in Appendix D.

Figures 1 and 2 are representative samples of the primary findings of the analysis. Figure 1 plots the standard deviation of speed measurements for one of the freeways studied as a function of vphpl. At flows between 0 to 500 vphpl the high variability in speed results from differences in individual driver control characteristics. Variance peaks again at volumes above 1200 vphpl where large variations in traffic flow arise due to flow instabilities characteristic of congestion. In the middle regime, between 500 and 1200 vphpl, variability is minimized as traffic tends to self regulate speed, and density of vehicles is not sufficient to be subject to unstable flow. The analysis of speed for arterials showed a similar ‘U’ shaped characteristic pattern of standard deviation of speed as a function of volume.
The sample standard deviations, as illustrated in Figure 1, can be used to determine minimum sample sizes. Figure 2 shows one such derivation for freeway speeds based on the results of the analysis. The primary finding is that minimum samples sizes for a various accuracy levels vary with volume. Previously, literature had suggested a constant 5 mph standard deviation suitable for any level of AADT. The analysis also derived characteristics relationships for volume as well, though the results were less striking. Appendix D contains a full description of the methodology and results. Minimum sample size specifications are derived for speed and volume for both freeways and arterials.

![Sample Size for Freeway Speed vs. Volume](image)

**Figure 2.** Minimum samples sizes for freeway speed detection. Chart depicts number of samples needed to obtain ±4 mph accuracy with 90% and 95% confidence based on observed sample standard deviation for various levels of per lane hourly volume.

### 3.5 Pilot Test Conference Calls

Two conference calls were hosted to help facilitate the pilot test activity and gather comments and insight from the participants. A conference call was hosted on July 26, 2007 to help initiate the pilot testing activities. The agenda consisted of reviewing project objectives and providing instructions and guidance to pilot test participants. Another conference call with pilot test participants and the project steering committee was hosted on December 20, 2007 after the majority of the pilot tests results were submitted and compiled. The purpose of the second conference call was to review the preliminary findings, solicit comments and feedback on the general conclusions drawn from the pilot test results, and to identify key areas for emphasis in the implementation guidelines. The summary and minutes from these conference calls are included in Appendix E.
CHAPTER 4: PILOT TEST RESULTS

Data, results, and lessons-learned from pilot testing exercise contributed to further refinement of the performance measures and formed the basis from which to develop implementation guidelines. Pilot testing participants provided a synopsis of their data collection indicating the locations, types of facilities, data collection techniques (where alternatives existed), and anticipated dates of data collection (or dates of data archive). When possible, participants estimated costs in terms of either labor hours, equipment utilized, or consulting costs, whichever was appropriate.

The objectives of the pilot testing activity were to:

- Evaluate the applicability of the definitions
- Evaluate the completeness of the data collection and processing procedures
- Evaluate the costs of the data collection process
- Assess the potential uses and benefits associated with the measures being collected
- Provide input into the development of guidelines that are practical and achievable.

Volunteer organizations were either state DOTs, metropolitan planning organizations (MPOs), or cities. Each organization varied in experience. Some volunteer organizations …

… already collected and processed data to obtain performance measures identical to (or very similar to) the performance measures of interest in this project. This activity provided them opportunity to standardize the calculations and showcase the utility of the performance measures.

… already had data collection procedures in place for other applications, but currently did not leverage these resources for developing the performance measures of interest in this project. This activity provided them the opportunity to experiment with reusing existing data or data collection processes for developing performance measures and report on the implementation challenges.

… were planning new data collection methods in support of performance measures and other applications. Involvement in this project was an opportunity to move that effort forward.

Depending on the circumstances of the organization, the extent and type of feedback from pilot testing varied. A summary of each organization’s experience in the collection, compilation, and reporting of performance measure is provided in the following sections specific to the performance measure tested. The data, summaries, sample reports and other material contributed from individual organizations during the pilot test are available the University of Maryland, Center for Advanced Transportation Technology in an electronic archive, an index of which is included in Appendix F.

A summary of the participants and the measures they tested is provided in Table 3.

13
<table>
<thead>
<tr>
<th>Organization</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<th>9</th>
<th>10</th>
<th>11</th>
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<tr>
<td>2 City of Overland Park, Kansas</td>
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<td>3 Colorado DOT</td>
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<tr>
<td>3 Florida DOT - District 4</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>4 Florida DOT - District 5</td>
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<td>5 Georgia Regional Transportation Authority (GRTA)</td>
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<td>X</td>
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<tr>
<td>6 Maricopa Assoication of Government (MAG)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>7 Maryland SHA</td>
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<tr>
<td>8 MetroPlan Orlando</td>
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<td>10 Southern Nevada RTC</td>
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<td>11 Virginia DOT</td>
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<tr>
<td>12 Wasatch Front Regional Council</td>
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<td>X</td>
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<td></td>
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<tr>
<td>13 Washington DOT</td>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
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</tr>
</tbody>
</table>
4.1 Customer Satisfaction Surveys

Volunteer organizations were requested to submit the results of customer satisfaction surveys in order to compare and contrast the performance measure definition with actual field experience. Due to the cycle length needed to program, design, and administer a survey, the pilot tests include results from surveys administered over the past three years, from 2005 through 2007. Some were specifically dedicated to obtaining customer satisfaction ratings for highway operations services and applications, while others were broader in scope but contained significant emphasis on highway operations and ITS topics.

Five organizations submitted results. Two were from state DOTs (Florida and Virginia), two from metropolitan planning organizations (Baltimore Metropolitan Council and MetroPlan Orlando) and one from a city (Overland Park, Kansas). The results represent a good sampling of types of organizations and survey purpose. Tables 4 and 5 summarize key characteristics of the five surveys, including the purpose, the sample size, cost, and the nature of the survey questions. The objective and scope of each customer satisfaction survey studied are highlighted below in more detail.

**Baltimore Metropolitan Council (BMC)**

The BMC survey was conducted to obtain a baseline measure of user perceptions on the management and operations of the transportation system in the Baltimore region. The intent of the BMC survey was to identify regional interests in order to develop collaborative strategies through plans and programs that will improve the quality of life and economic vitality of the Baltimore region. A unique aspect of the BMC survey is that it was multi-modal, assessing customer satisfaction of transit offerings as well as the roadway system. Also of note, the BMC survey was influenced by the original work by NTOC identifying Customer Satisfaction as a key performance measure.

**Florida DOT – District 4**

The results submitted by Florida DOT, District 4 were part of a larger statewide survey to explore usage of, attitudes toward, and perceptions of Florida Department of Transportation’s (FDOT) intelligent transportation system (ITS) services. The FDOT survey focused specifically on ITS services including customer awareness and satisfaction with their Road Ranger service, 511, and other methods and conduits of traveler information.

**MetroPlan Orlando**

The 2005 MetroPlan Orlando customer satisfaction survey was one of a series administered in recent years to monitor the state of public thinking about transportation issues in the Orlando metropolitan area. Previous surveys in 2001 and 2003 allow for trend analysis with respect to the results of the 2005 survey. The Orlando survey covers not only aspects of operation, but, similar to BMC, it touches on a wider array of transportation infrastructure issues including transit alternatives as well as preferred methods of financing.

**Overland Park, Kansas**
The customer satisfaction survey conducted by Overland Park (OP) was the most focused and application specific survey of those studied. OP surveyed residents from the area concerning the use of dynamic message signs (DMS) on the city’s local arterial streets. At the time of the survey, multiple DMS were installed and functional on various approaches at two major arterial intersections adjacent to a major freeway. The DMS were used to warn drivers of congestion on the major freeway as well as problems on the local arterials. The OP survey was a one-time survey to gauge the overall effectiveness of DMS, elicit feedback on specific aspects of the DMS (i.e., aesthetics, message content, route diversion, etc.), and determine if expanded deployment of DMS was viewed as a worthwhile investment.

**Virginia DOT (VDOT)**

VDOT has conducted customer satisfaction surveys for a number of years; however, there has never been a schedule or consistent focus on specific items. Recently, VDOT developed a plan to conduct surveys on a regular basis that will focus on specific functional and operational areas including: communications, traffic and incident management, responsiveness to citizen’s needs, planning, maintenance and construction of roads, and management of public funds. The first such survey was conducted in spring 2007.

Although the five sample surveys reflect a broad array of objectives, the methodologies employed by the five organizations contained many similarities. Common to all is the engagement of professional resources, either private businesses or university resources, to assist in the design of the survey, establish an appropriate sampling framework, and to perform all aspects of survey administration and data analysis. These findings reinforced the workshop recommendation that organizations should utilize professional services when conducting customer satisfaction surveys. Involvement of the transportation, ITS, or planning profession was limited primarily to defining the objective and sample population of the survey, selection of question topics, and providing technical assistance in terms of transportation expertise in formulating survey questions.

Surveys from all five organizations used various question types. The majority of questions were constructed to rate user response on an ordinal scale. Some of these used numerical values, for example “On a scale of 1 to 5, with one being strongly agree and five being strongly disagree …” In the majority of questions, the ordinal scale was with descriptive phases such as “Strongly agree, somewhat agree, neutral, disagree, strongly disagree” The majority of question were limited to 4 or 5 possible response categories.
TABLE 4  Summary of Customer Satisfaction Surveys

<table>
<thead>
<tr>
<th>Purpose of Survey</th>
<th>Survey Mechanism</th>
<th>Type of Operations and IT Services Surveyed</th>
<th>Engaged Professional Assistance</th>
<th>Number of Total Questions</th>
<th>Sample Size</th>
<th>Confidence Level / Error</th>
<th>Cost</th>
<th>Geographic Extents</th>
<th>Date</th>
<th>Survey Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baltimore Metropolitan Council</td>
<td>Telephone</td>
<td>Extent of Congestion Traffic Signal Operations Transportation Information</td>
<td>Yes</td>
<td>30</td>
<td>1003</td>
<td>95% / 3.1%</td>
<td>-</td>
<td>Five counties &amp; Baltimore City</td>
<td>May - June 2006</td>
<td>-</td>
</tr>
<tr>
<td>Florida DOT - District 4</td>
<td>Telephone</td>
<td>DMS 511 Road Rangers Radio Traffic Reports TV Traffic Reports Web Site</td>
<td>Yes</td>
<td>31</td>
<td>400</td>
<td>3.90%</td>
<td>-</td>
<td>Florida District 4</td>
<td>March 2006</td>
<td>-</td>
</tr>
<tr>
<td>MetroPlan Orlando</td>
<td>Telephone</td>
<td>Congestion Management Incident Management DMS Signal Coordination Travel Time Travel Time Reliability</td>
<td>Yes</td>
<td>76</td>
<td>840</td>
<td>-</td>
<td>-</td>
<td>Orlando metro area, 3 counties</td>
<td>Feb - Mar 2005</td>
<td>Previous surveys in 2001 &amp; 2003</td>
</tr>
<tr>
<td>Overland Park, KS</td>
<td>Mail and Telephone</td>
<td>DMS</td>
<td>Yes</td>
<td>22</td>
<td>527</td>
<td>95% / 4.5%</td>
<td>$7500 + 40 hours of staff time</td>
<td>City of Overland Park, KS</td>
<td>Jan - Feb 2007</td>
<td>One time survey</td>
</tr>
<tr>
<td>Virginia DOT</td>
<td>Telephone</td>
<td>Traffic Management Incident Response 511 Phone and Web CMS</td>
<td>Yes</td>
<td>44</td>
<td>1800</td>
<td>-</td>
<td>$ 51,200</td>
<td>Statewide</td>
<td>May 2007</td>
<td>Periodic (Every 2-3 Years)</td>
</tr>
</tbody>
</table>
# TABLE 5  Types of Questions Used in Customer Satisfaction Surveys

<table>
<thead>
<tr>
<th>Nature of Questions</th>
<th>Question Structure</th>
<th>Sample Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Service</strong></td>
<td><strong>Assessment of</strong></td>
<td><strong>Typical number of values for ordinal scale</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Frequency of Use</strong></td>
<td><strong>Satisfaction and/or Importance</strong></td>
</tr>
<tr>
<td><strong>Baltimore Metropolitan Council</strong></td>
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<td>✓</td>
</tr>
<tr>
<td>Extent of Congestion</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Traffic Signal Operations</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Transportation Information</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Florida DOT « District 4</strong></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>DMS 511</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Road Rangers</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Radio Traffic Reports</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>TV Traffic Reports</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Web Site</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>MetroPlan Orlando</strong></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Congestion Management</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Incident Management</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>DMS</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Signal Coordination</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Travel Time</td>
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<td>✓</td>
</tr>
<tr>
<td>Travel Time Reliability</td>
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<tr>
<td><strong>Overland Park, KS</strong></td>
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<tr>
<td>DMS</td>
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<tr>
<td><strong>Virginia DOT</strong></td>
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<td>✓</td>
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<tr>
<td>Traffic Management</td>
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<tr>
<td>Incident Response</td>
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<td>✓</td>
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<tr>
<td>511 Phone and Web</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>DMS</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Sample Questions</strong></td>
<td></td>
<td>Q18: How often have you experienced congestion on your way to or from work/school? Would you say ...? [Always</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Q20: Do you change your commute to work/school in any way as a result of congestion?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How often do you use the 511 service? [Frequently</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Have you ever been assisted by a Road Ranger unit? [P</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For the following statements, please tell me how important that issues is as a priority to you « very important, somewhat important, not too important, or not important at all.</td>
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<td>Clear highway accidents more quickly. Provide traffic information through hig.</td>
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<td>Q8. What do you think of the messages on these signs? Do you think they are: [ Very easy to understand</td>
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<td>Q10. Have you changed your route as a result of a message</td>
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<td>Q21: Prior to this interview, had you ever heard of or read about 511, 511 Virginia, or 511 Virginia.org? [P</td>
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<tr>
<td></td>
<td></td>
<td>Q25b: What prompted you to use 511? [Traffic</td>
</tr>
</tbody>
</table>
4.2 Incident Duration

As incident management systems are maturing in many metropolitan areas, incident duration is emerging as the base metric to determine effectiveness of programs. The pilot study collected examples of incident duration performance measures volunteered from various organizations and compared and contrasted them with each other and against the NTOC definition.

Four state DOTs (Florida, Virginia, Washington, and Maryland) provided samples of their incident duration performance measure reports derived from the data systems supporting their incident management programs. Overland Park, Kansas indicated that they were commencing incident management in 2007, including detailed logging and reporting of incidents on the city road network, but no data were available at the time of pilot testing.

Table 6 summarizes the incident management programs and incident duration reporting details. Highlights from each location are noted below.

**Florida DOT – District 4**
Florida District 4 is an early adopter of an incident management system being deployed statewide in Florida. Instituted in 2005, the reporting system is fully web-enabled and automatically generates weekly, monthly, and quarterly reports based on incident management activity logged into the system. Notable aspects include reporting of detection, verification, response, roadway clearance, and incident clearance times using intuitive horizontal stacked bar charts. Incident duration is categorized by time of day, accident severity, event type, and roadway. Benefit Cost Ratio (B/C) and Net Present Value (NPV) are calculated automatically in the quarterly and yearly reports. Also of note is the reporting of incident response statistics for each Road Ranger unit.

**Maryland State Highway Administration - MSHA**
The Coordinated Highways Action Response Team (CHART) is the highway incident management system of the MSHA. Functional since the mid 1990s, CHART has a well established incident management program and a rich data archive as a result of a unified, well-maintained, statewide data system that supports their incident management system. A yearly evaluation and benefit analysis has been performed based on incident duration performance measures by the University of Maryland. This evaluation uses incident duration statistics to place a monetary value of the benefits provided by the CHART system. Additionally, all CHART incident data is archived in the Regional Integrated Transportation Information System (RITIS) from which custom and pre-defined incident duration reports can be generated on-demand.

**Virginia DOT**
Virginia DOT currently uses the Virginia Operations Information System (VOIS) as the data source to assess incident duration based on time stamps of entry logs. Individual districts and operations centers use differing data systems to manage incidents. In some cases, data is manually entered into both the local system and VOIS. Incident timeline details may be lost in the process. VDOT is developing a new system that will allow
capture of specific milestones in each incident. Incident duration from VOIS is used to
determine the return on investment of VDOT’s incident management program.

**Washington DOT**
The Washington DOT reports incident duration measures quarterly as part of its gray
notebook reporting methodology. Unique to Washington DOT is the incorporation of
performance management goals in the area of incident management as part of a broader
effort called Government Management Accountability and Performance (GMAP).
Within the GMAP program, the specified target is a reduction in incident clearance times
of 5% for incidents lasting longer than 90 minutes. Washington DOT’s clear and
consistent reporting since 2002 of improvements in incident duration as a result of its
management program has been instrumental in securing funding for continued operation
and enhancements.

Implementation of the Incident Duration performance measure was generally consistent with the
performance measure definition, but subject to the limitations inherent in the data systems (for
example, as noted by the Virginia DOT). Various organizations differentiated themselves not in
the method of implementation of the measure, but rather in the reporting and use of the data as
highlighted above.

Mean incident duration was reported by all pilot test organizations. The February 2007
workshop suggested the use the median incident duration instead of the mean in order to limit the
influence of outliers on the central tendency. The Virginia DOT in their monthly performance
report provides a graph of both the mean and median incident duration, a sample of which is
shown in Figure 3. As illustrated in the graph, although the median may limit the influence of
outliers, its estimate of expected value of incident duration is artificially low. Median measures
perform best on symmetrically distributed data. Incident duration data follows an exponential
distribution, yielding itself poorly to median estimates of central tendency.

Costs for the implementation of incident duration performance measure were generally lacking
in the pilot test data. The incremental cost to compile and report incident duration is minimal
compared to the cost of operating an incident management system.
<table>
<thead>
<tr>
<th>Agency</th>
<th>Program History</th>
<th>Incident Duration Definition</th>
<th>Type and Frequency of Reporting</th>
<th>Duration Reported by:</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida DOT - District 4</td>
<td>Since 2005</td>
<td>The time when the first agency is notified</td>
<td>The time when all evidence of the incident is removed from travel and shoulder lanes</td>
<td># of Lanes Blocked</td>
<td>Incident Type</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reports are generated weekly and published on the SunGuide web interface (<a href="http://www.smartguide.com">www.smartguide.com</a>)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Washington DOT</td>
<td>Since 2002</td>
<td>The time that WSDOT learns of the event</td>
<td>Two Distinct Durations are Reported WSDOT External: When the last responder has left the scene</td>
<td>Incident duration measures used in statewide GMAP performance management program. Goal is a 5% reduction in incident duration for incident &gt; 90 minutes.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Statewide GMAP measure: The time when all disabled vehicles, debris and other blockages have been removed from the lanes and traffic can move again on all lanes in cooperation with the Washington State Patrol</td>
<td>Quarterly reports are generated and published through the gray notebook</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Virginia DOT</td>
<td>???</td>
<td>This system records the duration of the incident log, not the actual times of notification, verification, response and end of incident. The log is date stamped when it is opened and closed by operators. Therefore, the data represent an approximation of actual incident duration. VDOT is developing a new system that will allow capture of these specific milestones in each incident.</td>
<td>Results are published monthly in the systems operations performance report. Some stats are available through the VDOT Dashboard</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Maryland CHART</td>
<td>Since 1997</td>
<td>Incident open time (operator begins to input information)</td>
<td>Incident closed time (scene cleared time)</td>
<td>Yearly report focuses on evaluation and benefit of CHART operations</td>
<td>✓</td>
</tr>
</tbody>
</table>
All participants used incident duration information to support some type of cost-benefit analysis of their respective incident management system. In such reports, agencies attributed a dollar value to the time saved as a result of the incident management program. This cost-benefit analysis was used to justify and/or expand an incident management system, as noted by the Washington DOT submittal. Figure 4 shows an example of average incident duration comparisons with and without response from emergency assistance vehicle. The data for the chart was obtained from a yearly performance evaluation and benefit analysis of the Maryland CHART system performed by the University of Maryland. Reductions in secondary incidents as a result of efficient clearance of initial incidents are also reported as monetary benefits.

![Statewide Average and Median Incident Duration](image)

**Figure 3. Mean versus Median Incident Duration.** *Source: August 2007 Virginia System Operations Performance Report*

Additional resources in the development or enhancement of incident management systems (and related incident duration performance measures) include the National Traffic Incident Management Coalition (NTIMC) and its associated effort of the National Unified Goal (NUG) and the FHWA sponsored focus-state initiative on traffic incident management (TIM) performance measures. NUG is a unified national policy developed by major national organizations representing traffic incident responders, under the leadership of the NTIMC. The NUG encourages state and local transportation and public safety agencies to adopt unified, multi-disciplinary policies, procedures and practices that will dramatically improve the way traffic incidents are managed on U.S. roadways. Additional information is available at [www.timcoalition.org](http://www.timcoalition.org). The TIM focus state initiative involves 11 states in two separate (East/West) groups. It identifies measures that participating states can agree upon and initiate to gain experience in actually computing these measures over time. This initiative is ongoing. Once complete, a comprehensive set of recommendations and lessons-learned reports for use by all agencies involved in traffic incident management will be made available. Additional
The effect of CHART response on average incident duration.

Figure 4. Impact of Response Vehicle on Incident Duration. SOURCE: Compiled from University of Maryland’s 2006 Performance Evaluation of the Maryland State Highway Administration incident management system.

In summary, the pilot testing of incident duration resulted in the following guidelines:

- Effective performance measurement requires well-defined start and end times as noted in the definition.
- Additional metrics for effective and robust incident duration include:
  - Well-documented incident location so it can be tracked, analyzed and easily displayed on a map
  - Type and severity of incident
  - Responder information
  - Lane closure status, which can be a measure of severity
- Track the quality of the incident data as well as duration (completeness of data, percent of fields populated, etc.)
- Use mean duration as opposed to median due to the non-symmetric distribution
- Incident duration is an effective measure to determine monetary benefits of incident management programs
4.3 Traffic Flow Performance Measures

Traffic flow performance measures directly quantify the flow characteristics of the roadway based on physical measurements. Traffic flow performance measures encompass the following:

- **Travel Time – Facility & Trip**
- **Speed**
- **Recurring & Non-Recurring Delay**
- **Extent of Congestion – Spatial & Temporal**
- **Throughput – Person & Vehicle**
- **Travel Time - Reliability**

Common to all of these measures is the need for sensor data that quantifies travel-time, speed, and/or volume. As such, these measures share data collection methods and sensor detection technology. Pilot test results are first summarized by the data collection issues common to all measures, and then by data compilation and reporting aspects specific to individual measures. In most pilot test scenarios, a single data collection process provided the data from which multiple traffic flow performance measures were calculated.

4.3.1 Traffic Flow Data Collection

A variety of technologies were employed in the pilot testing. Table 7 summarizes attributes of the data collection systems employed to obtain speed, travel-time, and/or volume data needed to compile the various traffic flow performance measures for each organization. The table contains a description of the type and extent of facilities, the primary data collection technology, and the performance measures calculated. A brief summary of purpose, extent, and data collection issues encountered at each location are noted below. Full submittals are available in an electronic archive from the University of Maryland Center for Advanced Transportation Technology. An index to the archive is available in Appendix F.

**Colorado DOT**

The Colorado DOT (CDOT) has gathered travel time information on primary commute and recreational routes using floating car methods since 2000. In 2007, routes exhibiting volume to capacity ratios in excess of 0.85 were included in the program. CDOT contracts with a private firm to collect travel time using floating car methods. A minimum of eight floating car runs are made to characterize the AM and PM peak, and a mid-day off-peak period for commute routes. From this data, CDOT reports travel time, delay, throughput, and plans to estimate spatial extent of congestion beginning with the 2007 data set. Partial results from the 2007 program were submitted as examples. Complete data and the associated performance measure reports will be available in early 2008.

**Florida DOT, District 4**

FDOT District 4 is commencing operation of a new system in which volume, occupancy, and speed data will be obtained from sensors spaced every ½ mile within two freeway corridors. Travel times will be reported in 15 minute intervals for ~40 miles of interstate freeways spanning I-95 and I-595 near Miami. Traffic flow performance measures will be reported automatically on the SunGuide website along with their existing incident
management performance reports. Included with the FDOT District 4 data is an ITS Performance Measures report that provides details of all the measures to be reported once the system is fully deployed.

**Florida DOT, District 5**
The Florida Department of Transportation District Five (FDOT D5) monitors travel time on 135 centerline miles of principle arterials in Central Florida. Travel times are measured from reading and matching automated toll tags from a system of readers deployed specifically for travel time monitoring on the arterial network. Data from this system is used in the area’s 511 information network. Travel time data from this network was used to pilot test extent of congestion measures, both spatial and temporal, for an arterial network. The pilot test revealed the inadequacy of the ‘unconstrained travel time’ definition as applied to arterials. This prompted additional investigation resulting in a revised definition applicable to signalized arterials.

**Georgia Regional Transportation Authority (GRTA)**
GRTA submitted data and sample reports for travel time and travel time reliability measures on their network of freeways in the Atlanta metropolitan area. The Georgia DOT maintains a network of video-based fixed sensors at 1/3 mile intervals. Speed data from these sensors is used to calculate travel times on the network. The data collection and reporting processes have been in place since 2002, and the measures are published annually in the Transportation MAP report. The archive provides suitable data from which to effectively quantify the growth in congestion on a yearly basis.

As opportunity arises due to road construction and rehabilitation, the Georgia DOT experiments with alternative methods to provide speed and travel time data in a more cost effective method. Notable among these efforts is the use of Cellular Probe Data in lieu of redeployment of video-based sensors as a cost savings measure in one corridor. Although early in deployment, initial accuracy tests proved sufficient to continue deployment.[2]

**Maricopa Association of Governments (MAG)**
MAG provided sample data and compiled performance measure information for a network of heavily traveled freeway commuter routes in the Phoenix metropolitan area. The data used by MAG comes from a network of fixed sensors deployed and maintained by the Arizona DOT. Deployed since 2000, quality control and maintenance expense concerns required re-evaluation of the data collection system in 2005. As a result, MAG now receives data with guaranteed accuracy on a network of 58 sensors out of the originally deployed 500 sensors. From such data, MAG has begun to report speed, travel-time, extent of congestion, and throughput measures beginning with 2006 sensor data.

**Maryland State Highway Administration (MSHA)**
MSHA through its Coordinated Highway Action Response Team (CHART) program maintains a system of about 70 speed detectors throughout the Baltimore – Washington DC metropolitan area since 2002. The primary application of the data from the system is
a color-coded speed map available on the CHART web site (www.chart.state.md.us). Speed data from this system was piloted tested as a means to estimate travel time. The exercise revealed data quality issues that must be addressed in order to estimate travel time with sufficient accuracy for display on changeable message signs.

**Overland Park, Kansas**
Overland Park collects travel time data on its system of coordinated arterials each year using the floating car method. The primary purpose of the data is to evaluate signal timing. Data has been collected since 1994 and the results are reported yearly as an assessment of signal operations within the city. During at least two years, travel time data was also collected during periods when the traffic signals were not coordinated. This allowed the traffic division to observe and quantify the overall benefit of signal coordination. All floating car data is collected using staff resources.

**Southern Nevada Regional Transportation Commission (RTC)**
The Nevada DOT, working in cooperation with the Southern Nevada RTC, has successfully installed freeway monitoring devices on 15 centerline miles of freeway in the Las Vegas metropolitan area. Although work continues on installing these devices in other corridors, the RTC is capable of archiving the data and then retrieving it for performance measure calculations.

Data from eight centerline miles of I-15 between two system interchanges (I-215 and US 95 / I-515) were used for pilot testing purposes. In addition to the freeway detectors, this freeway section is equipped with ramp meters, closed circuit TV cameras, and dynamic message signs. The performance measures were compiled by RTC staff proficient in understanding freeway performance measures using desktop database and spreadsheet tools. It is intended that the data sets and procedures created during the pilot test would form a functional sample from which production procedures could be modeled and implemented in the center’s data processing system.

**Virginia DOT (VDOT)**
The pilot test data submitted from VDOT arises from two separate data collection systems. The primary data used for statewide monitoring comes from 216 continuous count stations distributed throughout the state that are polled every 15 minutes. This data is used to report speed and various throughput measures. A speed index performance measure developed by the University of Virginia is compiled using data from the continuous count stations. The speed index is used in conjunction with throughput data as aggregate measures of system performance.[3]

The second data collection system provides flow data using a network of fixed sensors on I-66 in Northern Virginia. This system is used to assess speed, travel time and extent of congestion measures in that corridor.

**Wasatch Front Regional Council (WFRC)**
The Utah DOT operates a sensor network in the Salt Lake City and Ogden metropolitan areas from which performance measures will be calculated. The Utah DOT is in the
process of acquiring analysis software which will have the capability to calculate performance measures based on available data. While still awaiting installation of the system, the WFRC provided a description of the anticipated performance measures, sample data, and example calculations to be implemented.

**Washington DOT**

The Washington DOT (WSDOT) reports mobility performance data on 38 of 52 tracked commutes in the Central Puget Sound region and two commutes in Spokane. WSDOT reports on average travel time, 95% reliable travel time, traffic volume, the duration of peak period congestion, and the percent of weekdays when average travel speeds fall below 35 mph. These routes are tracked for changes in traffic conditions on a yearly basis.

WSDOT relies primarily on loop detectors to collect traffic data. WSDOT has amassed a large archive of speed and volume data. This data is continuous in time, 24 hours per day 365 days per year, broad in geographic coverage, available for individual lanes or sets of lanes, and available in increments of time as short as 20 seconds. In the Puget Sound region, operational data are collected from more than 4,000 induction loops embedded in the pavement of the highway system at roughly 360 highway locations providing volume and occupancy data. Speed estimated from single loops is accurate to 5 or 10 mph in free-flow steady speed conditions. WSDOT also has 100 dual loop installations in the Puget Sound region, capable of providing speed data accurate to within 1 or 2 mph at ordinary driving speeds. The Washington State Transportation Center (TRAC) has developed detailed quality control procedures used to detect loop failures, exclude bad data, and support the level of accuracy that is needed for traffic management and for reporting traffic conditions.
<table>
<thead>
<tr>
<th>Agency</th>
<th>Type of Facilities</th>
<th>Data Collection Method or Technology</th>
<th>Extent of Data Collection / Study Area</th>
<th>History of Data Collection</th>
<th>Sampling Parameters</th>
<th>Performance Measures Assessed</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorado DOT</td>
<td>Commuter &amp; Recreational Corridors</td>
<td>Floating car</td>
<td>68 corridors (Length: 1 - 54 mi)</td>
<td>Since 2000 on some corridors</td>
<td>8 runs for each period</td>
<td>Speed, Travel Time, TT - Reliability, Recurring Delay, Non-Recurring Delay, Extent of Congestion, Throughput</td>
<td>Data collection for 2007 estimated at $318,000.</td>
</tr>
<tr>
<td>Florida DOT District 4</td>
<td>Freeway</td>
<td>Fixed Sensors Side-fire Radar</td>
<td>Two interstate corridors ~40 miles in length, I95 &amp; I 595</td>
<td>Initiated 2007 Data is polled every 20 seconds</td>
<td></td>
<td>Speed, Travel Time, TT - Reliability, Extent of Congestion</td>
<td>Initial applications will be color coded maps and travel time on signs</td>
</tr>
<tr>
<td>Florida DOT District 5</td>
<td>Arterial</td>
<td>Probe vehicle Toll Tag Transponders</td>
<td>135 mile arterial network, representing 74 corridors</td>
<td>Initiated 2007 Travel time from matched toll tags each minute</td>
<td></td>
<td>Speed, Travel Time, TT - Reliability, Extent of Congestion</td>
<td>Primary technical challenge was a calculation algorithm to account for high degree of sensor outages</td>
</tr>
<tr>
<td>Georgia Regional Transportation Authority (GRTA)</td>
<td>Freeway</td>
<td>Fixed Sensors Video Based</td>
<td>16 birectional corridors (Length: 4 - 15 mi)</td>
<td>Reported since 2002 Aggregated to 15 minute intervals</td>
<td></td>
<td>Speed, Travel Time, TT - Reliability, Extent of Congestion</td>
<td>AZ DOT provides data to MAG. Quality and maintenance concerns addressed in 2005 resulting in a higher quality data at the expense of a smaller network of</td>
</tr>
<tr>
<td>Maricopa Association of Government (MAG)</td>
<td>Freeway</td>
<td>Fixed Sensors Passive Acoustic Detectors &amp; Loops</td>
<td>6 corridors (Length: 8 - 10 mi)</td>
<td>Since 2000 Reported in 15 minute intervals</td>
<td></td>
<td>Speed, Travel Time, TT - Reliability, Extent of Congestion</td>
<td>Data quality control issues prevents use of sensor data for performance measures</td>
</tr>
<tr>
<td>Maryland SHA</td>
<td>Freeway</td>
<td>Fixed Sensors Side Fire Radar</td>
<td>70 Detectors throughout the Baltimore - DC area</td>
<td>Since 2002 5 minutes</td>
<td></td>
<td>Speed, Travel Time, TT - Reliability, Extent of Congestion</td>
<td>Data quality control issues prevents use of sensor data for performance measures</td>
</tr>
<tr>
<td>Overland Park, KS</td>
<td>Arterial</td>
<td>Floating car</td>
<td>25 corridors (Length: 0.25 - 3 mi)</td>
<td>1994 to 2007 10 runs per direction</td>
<td></td>
<td>Speed, Travel Time, TT - Reliability, Extent of Congestion</td>
<td>Data collection requires 150 hours of staff time yearly</td>
</tr>
<tr>
<td>Southern Nevada Regional Transportation Commission</td>
<td>Freeway</td>
<td>Fixed Sensors Side Fire Radar &amp; Loop Detectors</td>
<td>8 centerline miles on I-15 in Las Vegas between I-215 at the south and US 95 at the north</td>
<td>Since Sept 2006 Aggregated to 15 minute intervals</td>
<td></td>
<td>Speed, Travel Time, TT - Reliability, Extent of Congestion</td>
<td>Data sets and procedures from the pilot test are intended to be used as a functional sample for future production implementation.</td>
</tr>
<tr>
<td>Virginia DOT</td>
<td>Freeway</td>
<td>Fixed Sensors Dual Loops</td>
<td>Statewide monitoring from 216 permanent count stations</td>
<td>Archive available since 2003 Polled every 15 minutes</td>
<td></td>
<td>Speed, Travel Time, TT - Reliability, Extent of Congestion</td>
<td>Costs for permanent count stations are available</td>
</tr>
<tr>
<td>Fixed Sensors: Loop</td>
<td></td>
<td></td>
<td>6 corridors on I66 in Northern VA (Length: 7 - 11 miles each)</td>
<td></td>
<td></td>
<td>Speed, Travel Time, TT - Reliability, Extent of Congestion</td>
<td>Costs for permanent count stations are available</td>
</tr>
<tr>
<td>Virginia DOT</td>
<td>Freeway</td>
<td>Fixed Sensors Loop</td>
<td>---</td>
<td>Continuous</td>
<td></td>
<td>Speed, Travel Time, TT - Reliability, Extent of Congestion</td>
<td>Utah DOT is currently implementing new analysis software. WFRC provided sample calculations of recommended/intended measures</td>
</tr>
<tr>
<td>Wasatch Regional Front Council (WFRC)</td>
<td>Freeway</td>
<td>Fixed Sensors</td>
<td>---</td>
<td>Continuous</td>
<td></td>
<td>Speed, Travel Time, TT - Reliability, Extent of Congestion</td>
<td>Utah DOT is currently implementing new analysis software. WFRC provided sample calculations of recommended/intended measures</td>
</tr>
<tr>
<td>Washington DOT</td>
<td>Freeway</td>
<td>Fixed Sensors Loop Detectors</td>
<td>---</td>
<td>Continuous</td>
<td></td>
<td>Speed, Travel Time, TT - Reliability, Extent of Congestion</td>
<td>WSDOT uses an extensive quality control plan for maintenance, calibration, and error checking developed by University of Washington TRAC.</td>
</tr>
</tbody>
</table>

**TABLE 7** Summary of Data Collection for Traffic Flow Performance Measures
The methods and technology for collecting traffic flow data for performance measures purposes is contrasted in Table 8. Three primary classes of data collection are represented in the pilot test submittals: fixed sensor, floating car, and vehicle probe technologies.

A fixed sensor refers to any type of electronic sensing device installed in a specified location to collect speed, volume and/or occupancy data. They are ‘fixed’ in that they measure traffic attributes at a single point along the roadway. Data based on fixed sensors is predominant in the pilot tests. Many metropolitan areas have deployed fixed sensor networks as part of their ITS infrastructure investments beginning in the late 1990s. Although a variety of technologies are available, inductive loops are the oldest and most prevalent. Single loop configurations directly measure volume and occupancy. Speed is inferred from single loop configurations by assuming an average vehicle length. As noted by WSDOT, single loops provide a speed estimate that is accurate to 5 or 10 mph in free-flow steady speed conditions. Such accuracies are indicative of any technology whose base measurements are volume counts and occupancy. Inaccuracies arise not from the electronic sensing equipment, but from the uncertainties inherent in converting volume and occupancy into speed data. Dual loop arrangements measure speed directly, achieving accuracies of 1 to 2 mph.

### TABLE 8 Contrast of Data Collection Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Sub-Method</th>
<th>Base Measurements</th>
<th>Typical Sampling Parameters</th>
<th>Freeway Use</th>
<th>Arterial Use</th>
<th>Performance Measures Supported</th>
<th>Costs</th>
<th>Primary Deployment Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Sensor</td>
<td>Single Loops</td>
<td>Volume &amp; Occupancy</td>
<td>5 Minute</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>$7500 to $20000 per site depending on availability of existing structures</td>
<td>Costs, Sensor Density, Maintenance, Quality Control</td>
</tr>
<tr>
<td></td>
<td>Dual Loops</td>
<td>Volume, Speed</td>
<td>5 Minute</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>$7500 to $20000 per site depending on availability of existing structures</td>
<td>Costs, Sensor Density, Maintenance, Quality Control</td>
</tr>
<tr>
<td></td>
<td>Cross-Fire Radar</td>
<td>Volume, Occupancy, &amp; Speed</td>
<td>5 Minute</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>$7500 to $20000 per site depending on availability of existing structures</td>
<td>Costs, Sensor Density, Maintenance, Quality Control</td>
</tr>
<tr>
<td></td>
<td>Video Cameras</td>
<td>Volume, Occupancy &amp; Speed</td>
<td>5 Minute</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>$7500 to $20000 per site depending on availability of existing structures</td>
<td>Costs, Sensor Density, Maintenance, Quality Control</td>
</tr>
<tr>
<td>Floating Car</td>
<td>GPS Instrumented</td>
<td>Travel Time</td>
<td>8-10 Runs per year, per corridor</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>Budget $300 to $500 per mile</td>
<td>Minimum Sampling Parameters</td>
</tr>
<tr>
<td>Vehicle Probe</td>
<td>Toll-Tag Transponder</td>
<td>1-5 minute</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>$15000 per site per direction (exclusive of structures)</td>
<td>Density of Toll- Tags and Cost of Equipment</td>
</tr>
<tr>
<td></td>
<td>Fleet GPS Data</td>
<td>Travel Time</td>
<td>5 - 15 minutes</td>
<td>✓</td>
<td>?</td>
<td>X</td>
<td>$500 - $1000 / mile / year</td>
<td>Data Latency and Sampling Density</td>
</tr>
<tr>
<td></td>
<td>Cell Phone Probes</td>
<td>Travel Time</td>
<td>1-10 minutes</td>
<td>✓</td>
<td>?</td>
<td>X</td>
<td>$500 - $1000 / mile / year</td>
<td>Accuracy, Privacy, and Business Model Sustainability</td>
</tr>
</tbody>
</table>

Data from fixed sensor networks share common attributes. Because speed is measured at a particular point in the roadway, fixed sensors are effective only in places where spot speed measurements are a good indicator of overall traffic flow. This assumption is valid in most freeway environments. The progression and quality of traffic flow on arterials, however, is dependent primarily on signal delay at intersections. Spot speed measurements either between signals or within intersections provide insufficient information to assess travel time or delay on
arterials. As such, fixed sensors networks are not recommended for assessing space-mean speed or travel time on arterial networks as reflected in Table 8. (Note: Fixed sensors are still effective to measure volume on such roadways.)

Installation costs for fixed sensor network are estimated between $7500 and $20,000 per site. The range in cost is due primarily to extent to which existing infrastructure can be reused. Reuse of existing poles and sign trusses reduce cost, as well as reuse of existing power and communications feeds. Methods and technology that allow for reuse of existing infrastructure, though more expensive, may prove the more cost effective overall. The density of fixed sensors ranged from 1/3 mile up to 3 miles on some networks, with ½ mile and 1/3 mile being the most prevalent as shown in Table 9. The relationship between sensor density and accuracy of travel time measurements has been researched in previous studies, as well as the relationship between travel time accuracy and the type of algorithm to convert spot speed measurements to travel time. However, the pilot test indicated that most organizations use a relatively simple method for conversion from speed to travel time, and that the primary challenge for obtaining accurate travel time estimates were related to quality control issues as will be discussed later. Pilot test results indicated that the primary benefit from high sensor density was redundancy in the event of sensor outages.

**TABLE 9  Fixed Sensor Spacing Observed in Pilot Test Results**

<table>
<thead>
<tr>
<th>Agency</th>
<th>Sensor Spacing</th>
<th>Data Collection Method or Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida DOT District 4</td>
<td>1/2 mile</td>
<td>Side-fire Radar</td>
</tr>
<tr>
<td>Georgia Regional Transportation Authority</td>
<td>1/3 mile</td>
<td>Video Based</td>
</tr>
<tr>
<td>Maricopa Association of Government</td>
<td>2-3 miles</td>
<td>Passive Acoustic Detectors &amp; Loops</td>
</tr>
<tr>
<td>Maryland SHA</td>
<td>1.5 to 3 miles</td>
<td>Side-fire Radar</td>
</tr>
<tr>
<td>Southern Nevada RTC</td>
<td>1/3 mile</td>
<td>Side-fire Radar &amp; Loop Detectors</td>
</tr>
<tr>
<td>Washington DOT</td>
<td>1/2 mile</td>
<td>Loop Detectors</td>
</tr>
</tbody>
</table>
Information from the pilot test indicated that a proactive, well-funded maintenance and quality control program is required to ensure the usability of data from such networks. In its absence, confidence in measurement accuracy quickly erodes. Pilot test results submitted by WSDOT, MAG (Arizona DOT), GRTA (Georgia DOT), and MSHA, all organizations with multiple years of experience operating and maintaining sensor networks, all reflect on this issue. WSDOT uses a number of procedures to identify loop failures quickly and flag suspect data in its analysis programs. GRTA’s travel time algorithm uses a complex averaging methodology to obtain travel time from speed sensor data provided by the Georgia DOT. The primary reason for the complex algorithm is the high rate of sensor outages within the network. Arizona DOT (the supplier of base data to MAG), recently downsized the number and extent of sensors in the Phoenix area in order to guarantee the accuracy of data on a smaller network within a limited budget. Data quality issues on MSHA’s network of fixed sensors deployed since 2002 has prevented the speed data from being used to estimate travel time within allowable error limits.

The two remaining methods reported in the pilot tests directly measured travel time by tracking a sample of the vehicles in the traffic stream. Travel time data collection performed by CDOT and Overland, Kansas relied on floating car data collection methods. The dates and times of sampling were chosen to be representative of average conditions for the period of interest. Sample size (the number of floating car runs within a given period of interest) was determined to ensure that the results are statistically representative of the population. Minimum sample sizes as determined from inherent standard deviation of traffic flow are directly applicable. Floating car methods are not adaptable to assess travel time reliability and non-recurring delay due to the amount of data required for such measures.

Floating car and vehicle probe methods provide direct measures of travel time. As such, these methods are applicable to arterials as well as to freeway environments as indicated in Table 8. Test sites utilizing either floating car or vehicle probe methods included arterial networks. However, unlike fixed sensors, such methods lack volume data which must be collected using other methods if needed. The pilot test results from Florida District 5 provide a case study of state-of-the-art vehicle probe technology supporting performance measures on an arterial network. The toll-tag probe data allowed for continuous monitoring of travel time and calculation of extent of congestion. The data supports the 511 travel information application available in the region. However, due to the probe nature of the technology, the system lacks throughput data of comparable extent and quality.

Although not reflected in the pilot test data, technology advancements in vehicle probe techniques are providing additional alternatives to fixed sensor networks. These alternatives include travel time data services derived either from fleet GPS data probes or cell phone probe techniques. Attribute summaries for Fleet GPS data and Cell Phone Probe technology are included in Table 8 based on recent projects at the Wisconsin DOT, I-95 Corridor Coalition and the Georgia DOT. Although still considered unproven, such technologies are theoretically capable of monitoring traffic flow on large geographic extents at a much reduced cost and without the need to deploy additional sensing equipment in the right-of-way. Probe techniques are proving viable for freeway monitoring based on demonstration data and recent deployment results.[2] Effectiveness on arterials has yet to be verified with field data.
4.3.2 Travel Time, Speed and Throughput Performance Measures

Speed, travel time, and throughput form the base data from which to calculate the remaining traffic flow performance measures such as delay, extent of congestion, and reliability. As such, issues related to compilation and reporting of these measures also impact the compilation and reporting of derivative measures.

Travel Time - Facility

Table 10 summarizes the pilot test results for those organizations reporting Travel Time – Facility as a performance measure. Key outcomes of the pilot test results for travel time include:

- Travel time is the foremost indicator of the quality of traffic flow currently in use. All organizations that submitted any type of traffic flow data developed travel time performance measures (or indicated that travel time would be a primary output in the case of Southern Nevada RTC and WFRC).
- Travel time is a prime indicator of congestion. The primary application of the travel time measure for half of the pilot test submittals was for congestion tracking.
  - Travel time is typically summarized in 15 minute intervals during peak periods of traffic, such as AM and PM rush hours.
  - Peak periods differ for various regions and networks. Most coincide with typical AM/PM commute patterns, but exceptions exist particularly for regions with large recreational industries such as Colorado and Las Vegas. Peak periods must be assessed individually.
- Direct measures of travel time are effective on arterial networks. The data submitted by Florida District 5, Overland Park, and Colorado measured performance on signalized arterials for various applications. Spot speed measurements are not effective in estimating travel time on arterials.
- All travel time data submitted was for either freeway or arterial performance. No end-to-end travel time data, as addressed in the ‘Travel Time – Trip’ performance measure were reported.

As an indicator of congestion, travel time was typically reported annually using 15 minute aggregation intervals during peak hours to convey the growth and location of congested areas. A simple, but effective graphical display of congestion monitoring using travel time measures is used by GRTA in its annual Transportation MAP report available online at http://www.grta.org under the “Mobility” section. A sample of the graphic is reproduced in Figure 5 for a specific commute route. This simple format effectively conveys the growth in congestion both in terms absolute travel time and in the spread of the peak period from year to year.
### TABLE 10  Summary of Travel Time Performance Measures during Pilot Testing

<table>
<thead>
<tr>
<th>Agency</th>
<th>Type of Facilities</th>
<th>Primary Application</th>
<th>Reporting Frequency &amp; History</th>
<th>Periods of Reporting</th>
<th>Reporting Costs</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorado DOT</td>
<td>Urban &amp; commuter corridors</td>
<td>Congestion Tracking</td>
<td>Annually</td>
<td>Peak hours: 7 AM - 9 AM, 4 PM - 6 PM; Off-peak hours: 11 AM - 1 PM</td>
<td>Reporting costs included in data collection contract of $318000</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>Recreational corridors</td>
<td></td>
<td></td>
<td>Peak hours: 11:30 AM - 5:30 PM; Off-peak hours: 9:30 AM - 11:30 AM, 5:30 PM - 7:30 PM</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Florida DOT District 4</td>
<td>~40 Miles from I-95 nd I-595 near Miami</td>
<td>Traveler Information - travel time via SmartGuide website</td>
<td>In development</td>
<td>Continuous - Realtime</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Florida DOT District 5</td>
<td>135 centeraline miles of arterials in central Florida (Orlando area)</td>
<td>Traveler Information through the 511 System</td>
<td>Continuous through the 511 system</td>
<td>Continuous - Realtime</td>
<td>---</td>
<td>Extensive travel time reporting on a large arterial network</td>
</tr>
<tr>
<td>Georgia Regional Transportation Authority (GRTA)</td>
<td>16 major freeway commuting corridors in the Atlanta metropolitan area</td>
<td>Congestion Tracking</td>
<td>Annual Report since 2002, available on the internet</td>
<td>Travel time is reported every 15 minutes for the AM Peak: 6 AM -10 AM and PM Peak: 3 PM - 7 PM</td>
<td>$12,000 consulting fees plus an additional 80 staff hours annually</td>
<td>Exceptional clarity in use of graphics to display annual growth of travel time</td>
</tr>
<tr>
<td>Maricopa Association of Government (MAG)</td>
<td>6 heavy volume freeway commuter corridors in the Phoenix metro area</td>
<td>Congestion Tracking</td>
<td>Annual Congestion Report</td>
<td>Peak hours: 5 AM - 10 AM, 2 PM - 7 PM</td>
<td>62 staff hours annually</td>
<td>---</td>
</tr>
<tr>
<td>Maryland SHA</td>
<td>Freeway network in the Baltimore - DC metro area</td>
<td>Travel time on Changeable Message Signs</td>
<td>Under development</td>
<td>Continuous - Realtime</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Overland Park, KS</td>
<td>Network of arterials in the city of Overland Park, KS</td>
<td>Assessment of Signal Coordination</td>
<td>Yearly Reporting since 1994</td>
<td>Travel Time is sampled yearly with floating cars, and reported for the AM Peak: 7 AM - 9 AM PM Peak: 4:30 PM - 6 PM</td>
<td>70 hours/year of staff time to compile annual report</td>
<td>Data also includes travel time without signal coordination</td>
</tr>
<tr>
<td>Southern Nevada RTC</td>
<td>Portion of freeway network in Las Vegas, NV</td>
<td>Congestion Tracking</td>
<td>The RTC is experimenting with various measures and reporting methods as functional examples for production.</td>
<td>Pilot results will serve</td>
<td>Data from the sensor network is currently reported as a distribution over speed and volume ranges.</td>
<td>---</td>
</tr>
<tr>
<td>Virginia DOT</td>
<td>I-66 in Northern Virginia</td>
<td>Traveler Information: Travel time on website</td>
<td>Under development</td>
<td>AM &amp; PM Peak, and 24 hour</td>
<td>$15,000 initial cost plus $50,000/year in staff time</td>
<td>---</td>
</tr>
<tr>
<td>Washington DOT</td>
<td>Freeway commuting routes, 52 in the Puget Sound area, and two in Spokane</td>
<td>Congestion Performance Measures</td>
<td>Annually</td>
<td>Peak hours: 6 AM - 9 AM, 3 PM - 7 PM</td>
<td>---</td>
<td>Consistent, statewide monitoring and reporting methodology via the Gray Notebook</td>
</tr>
<tr>
<td>WFRC</td>
<td>Freeway network</td>
<td>Congestion Tracking</td>
<td>Utah DOT is currently implementing new analysis software. WFRC provided sample calculations of recommended/intended measures</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
Figure 5. Sample Travel Time Illustration. Source: Transportation MAP report published annually by Georgia Regional Transportation Authority.

Speed

Table 11 summarizes the pilot test results for those organizations reporting Speed as a performance measure. Key outcomes of the pilot test results for speed include:

- The primary application was the use of speed data from a fixed-sensor network to color code a speed map for a public traveler information web site.
- Speed data from Virginia DOT’s continuous count stations is used to calculate a speed index. This is a metric developed by the University of Virginia specifically for implementation by VDOT as an indicator of statewide congestion. [3]
- Data from continuous count stations are reused for congestion monitoring purposes. Both VA and MSHA use or intend to use continuous count stations that traditionally serve the planning community for operations purposes.
TABLE 11 Pilot Test Results for Speed as a Performance Measure

<table>
<thead>
<tr>
<th>Agency</th>
<th>Primary Application</th>
<th>Type of reporting</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDOT D4</td>
<td>Real-time speed map on web site</td>
<td>Continuous - web based</td>
<td>Additional applications include annual mobility report, calibrating/validating travel demand forecasting models</td>
</tr>
<tr>
<td>Maricopa Association of Government</td>
<td>Real-time speed map on web site</td>
<td>Continuous - web based</td>
<td>Maryland is investigating use of continuous count station data for operations purposes</td>
</tr>
<tr>
<td>Maryland SHA</td>
<td>Real-time speed map on web site</td>
<td>Continuous - web based</td>
<td>Maryland is investigating use of continuous count station data for operations purposes</td>
</tr>
<tr>
<td>Virginia DOT</td>
<td>Statewide congestion monitoring with use of Speed Index</td>
<td>Annual Congestion Report</td>
<td>Data comes from the continuous count stations and is available to operations in real time at 5 minute intervals</td>
</tr>
</tbody>
</table>

Throughput Measures: Vehicle & Person

Table 12 contains a summary of the results submitted for throughput measures. Table 12 lists only those organizations with active reporting systems. WFRC, and Florida District 4 indicated the intent of reporting throughput measures, but these systems are still in development. Methods and technology to collect volume counts for vehicles are well established. Throughput metrics, particularly in the planning environment, are used to support long range planning, travel demand modeling, HPMS and other applications.

Key outcomes of the pilot test results for throughput measures include:

- Volume data are essential for the computation of other measures.
- Vehicle throughput as an operational performance measure is an effective indicator of facility utilization. WSDOT uses vehicle throughput to assess lost capacity due to congestion and is reported annually as part of the Gray Notebook. The measure is used to graphically illustrate locations on the freeway network where congestion diminished existing freeway capacity. [See illustration in ‘Extent of Congestion’ summary.]
- Person throughput measures require periodic, location specific occupancy surveys to obtain customized occupancy factors to apply to traffic volume counts.
- Person throughput measures are effective to assess performance of HOV lanes.
<table>
<thead>
<tr>
<th>Agency</th>
<th>Vehicle</th>
<th>Person</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Extent</strong></td>
<td><strong>Utility</strong></td>
<td><strong>Cost</strong></td>
</tr>
<tr>
<td>Colorado DOT</td>
<td>72 hour counts using tube/radar in conjunction with the floating car runs for 68 corridors (urban, commuter, &amp; recreational)</td>
<td>Included in the corridor report and necessary for delay calculations</td>
</tr>
<tr>
<td>Maricopa Association of Government</td>
<td>Same network and extent as other measures, 26 locations on 6 selected corridors</td>
<td>Annual mobility report, calibrating/validating travel demand forecasting model</td>
</tr>
<tr>
<td>Southern Nevada RTC</td>
<td>~ 8 mile portion of freeway network in Las Vegas, NV</td>
<td>The RTC system is still in development. The system reports throughput as percentages in various volume ranges per section on a hourly basis to help identify congestion patterns.</td>
</tr>
<tr>
<td>Virginia DOT</td>
<td>Statewide, 216 dual loop count stations</td>
<td>Used in conjunction with speed index to assess system’s performance. Develop factors to create AADT and VMT estimates</td>
</tr>
<tr>
<td>Washington DOT</td>
<td>Data is currently collected on most major freeways in the Puget Sound Region at approximately ½ mile intervals.</td>
<td>Volume measures are used to assess maximum throughput productivity, a primary congestion metric. Vehicle throughput is used in the Gray Notebook report distributed once/year.</td>
</tr>
</tbody>
</table>

**TABLE 12** Pilot Test Results for Throughput-Vehicle and Throughput-Person
4.3.3 Extent of Congestion Measures – Spatial and Temporal

Table 13 summarizes the pilot test results for Extent of Congestion Measures. Extent of Congestion, either Spatial or Temporal, are derivative measures primarily of travel time. Volume data may be used for weighting purposes in the calculations. Key outcomes of the pilot tests of Extent of Congestion include:

- Extent of Congestion measures as defined by NTOC were only recently implemented (as with the Maricopa Association of Governments) or being experimentally tested. No organization has a history of reporting Extent of Congestion measures as defined by NTOC prior to 2007.
- Some organizations have comparable measures that attempt to capture the geographic and time extents of congestion. Various thresholds and definitions for congestion are in use. A commonly used metric is the percent of time speed falls below 35 MPH as demonstrated in the WSDOT gray notebook reports. Assuming an unconstrained travel time equivalent to 60 MPH, a corresponding increase in travel time would be ~70%.
- Graphics used to depict extent of congestion frequently plot either a travel time or speed index versus time of day as an indicator of extent of congestion along a corridor.
- For arterial networks, the proposed definition of ‘unconstrained travel-time’ was inadequate. Attempts to define unconstrained travel time based on off-peak periods fail due to varying signal timing strategies throughout the day. Off-peak travel time may be substantially greater if signal timings are chosen to maximize access to side streets during off-peak hours.
- Using data submitted from Florida District 5, a definition of unconstrained travel for arterials equal to 30% greater than the speed limit equivalent travel time produced acceptable results. See Figure 6 for graphical depiction of the analysis.
- Travel time and speed are reciprocal in nature, which can cause confusion and inconsistencies in computation. Referring to Figure 7, a 30% reduction in speed corresponds to an approximate 43% increase in travel time.

The results of the pilot tests for extent of the extent of congestion measures revealed that the current NTOC definition may not provide the utility needed to quantify spatial and temporal extents of congestion. However, no equivalent measure has proliferated. Each entity appears to be experimenting with various combinations of travel time, speed, and throughput to define an effective congestion measure. Of particular note is the Washington DOT’s capacity utilization concept, a sample of which is shown in Figure 8. This measure is based on the percentage of capacity lost due to congestion, and is referred to as ‘Lost Productivity.’
<table>
<thead>
<tr>
<th>Agency</th>
<th>Facility Type</th>
<th>Spatial</th>
<th>Temporal</th>
<th>Description of Data Set</th>
<th>Definition of Unconstrained Travel Time</th>
<th>Congestion Threshold</th>
<th>Reporting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorado DOT</td>
<td>Arterial &amp; Freeway</td>
<td>✓</td>
<td></td>
<td>135 Centerline Miles of arterials in the Orlando metropolitan area. 2006 travel times from automated toll tag technology are used to estimate extent of congestion. Measures. 1.3 times the travel time at posted speed. 30% Greater than unconstrained travel time.</td>
<td></td>
<td></td>
<td>Experimental Results</td>
</tr>
<tr>
<td>Florida District 5</td>
<td>Arterial</td>
<td>✓ ✓</td>
<td></td>
<td>Using 2006 data from Tuesdays, Wednesday and Thursday (155 core days), spatial congestion is estimated for each corridor for every 15 minutes during peak periods. Temporal Congestion is defined as the percentage of peak period during which spatial congestion congested time periods out of the entire peak period. Monthly averages. 85th Percentile of off-peak travel time. 30% Greater than unconstrained travel time.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maricopa Association of Government (MAG)</td>
<td>Freeway 6 major commuter corridors</td>
<td>✓ ✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Results have been used in the MAG annual freeway mobility report. However, the previous congestion definition was based on speeds, using “speed&lt;=35 mph and speed&lt;=50 mph” as the thresholds for severe congestion and congestion respectively.</td>
</tr>
<tr>
<td>Southern Nevada RTC</td>
<td>Freeway Portion of LasVegas freeway system</td>
<td>✓ ✓</td>
<td></td>
<td></td>
<td>In Development, to be reported as part of the RTC-FAST system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virginia DOT</td>
<td>Freeway I86 in Northern Virginia</td>
<td>✓ ✓</td>
<td></td>
<td></td>
<td>In Development, to be reported on the VDOT Dashboard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washington DOT</td>
<td>Freeway 44 Mile Section of I5 passing through Seattle</td>
<td>✓ ✓</td>
<td></td>
<td>Extent of congestion was assessed on I5 using data sets from 2004 and 2006 for comparison and contrast.</td>
<td>Posted Speed</td>
<td>70% of Posted Speed</td>
<td>Reports (1) Percent of Days when speeds were less than 35 MHP and (2) lost capacity due to congestion based on maximum throughput conditions at 51 MPH. Calculation of NTOC extent of congestion was experimental.</td>
</tr>
</tbody>
</table>
Figure 6. Temporal Extent of Congestion on an Arterial Network. Unconstrained travel time determined as 30% greater than the speed limit equivalent travel time. 

**SOURCE:**
Data obtained from Florida DOT District5

Figure 7. Spatial Extent of Congestion Based on 30% Reduction in Speed. 

**SOURCE:** Contributed by Washington DOT during pilot test.
Figure 8. Loss of Productivity congestion measure based on throughput data. SOURCE: Washington DOT Gray Notebook Sept 30, 2006.
4.3.4 Travel Time - Reliability

Table 14 summarizes the information submitted during the pilot test concerning the Travel Time – Reliability measure. Key outcomes of the pilot tests include:

- All organizations implemented the reliability measure in full agreement with the definition. The explicit nature of the definition of travel time reliability provides for consistent implementation across various organizations.
- Metrics for reporting reliability in the pilot data included 95th percentile travel time, Planning Time Index (PTI), and Buffer Time Index (BTI).

### TABLE 14 Pilot Test Results for Travel Time - Reliability

<table>
<thead>
<tr>
<th>Agency</th>
<th>Type of Facilities</th>
<th>Reporting Frequency &amp; History</th>
<th>Periods of Reporting</th>
<th>Unit of Measure Reported</th>
<th>Reporting Costs</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georgia Regional Transportation Authority</td>
<td>16 major freeway commuting corridors in the Atlanta metropolitan area</td>
<td>Annual Report since 2002, available on the internet</td>
<td>15 minute intervals during peak periods: 6 AM - 10 AM and 3 PM - 7 PM</td>
<td>✓</td>
<td>✓</td>
<td>$12,000 consulting fees plus an additional 80 staff hours annually for all measures</td>
</tr>
<tr>
<td>Maricopa Association of Government</td>
<td>6 heavy volume freeway commuter corridors in the Phoenix metro area</td>
<td>Annual Congestion Report</td>
<td>15 minute intervals during peak periods: 5 AM - 10 AM and 2 PM - 7 PM</td>
<td>✓ ✓</td>
<td>✓</td>
<td>62 staff hours annually (all measures) Included as a standard measure in travel time reporting</td>
</tr>
<tr>
<td>Southern Nevada RTC</td>
<td>Portion of freeway network in Las Vegas, NV</td>
<td>In Development, sample calculation from pilot study will serve a functional sample for later production.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washington DOT</td>
<td>Freeway commuting routes, 52 in the Puget Sound area, and two in Spokane</td>
<td>Annual report and also on its interactive “Calculate Your Commute” website.</td>
<td>5 minute intervals during peak periods: 6 AM - 9 AM and 3 PM - 7 PM The five-minute interval with the highest average travel time value is used for reporting of reliability measures.</td>
<td>✓</td>
<td></td>
<td>Reports reliability stats only on commutes experiencing congestion, 38 of the 52 routes in the 2007 report.</td>
</tr>
</tbody>
</table>
4.3.5 Recurring and Non-Recurring Delay

Table 15 summarizes the information submitted during the pilot test concerning delay measures. Key outcomes of the pilot tests of Delay measure include:

- Delay is frequently used to assess a monetary value (or penalty) for the adverse effects of congestion.
- Varying definitions of unconstrained travel time are in use. WSDOT uses a travel time equivalent of maximum throughput, which is approximately 51 MPH. Colorado uses off-peak travel times, which creates problems for arterial networks. [See discussion of alternative definition of ‘Unconstrained Travel Time’ for arterials in the Extent of Congestion results.] WFRC intends to use posted speed, or equivalent based on functional class of roadway.
- Metrics and aggregation level of reporting vary, though this does not appear to present a problem due to the cumulative nature of the delay metric.
- No samples of Non-recurring Delay were submitted in the pilot tests.

### TABLE 15  Pilot Test Results for Recurring Delay

<table>
<thead>
<tr>
<th>Agency</th>
<th>Facility Type</th>
<th>Measures Reported</th>
<th>Definition of Unconstrained Travel Time</th>
<th>Reporting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorado DOT</td>
<td>Arterials &amp; Freeways Commuter and recreation corridors</td>
<td>Annual vehicle hours per route</td>
<td>Travel time during off-peak period</td>
<td>Annual reports for each corridor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annual person hours per route</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annual congestion cost per route</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WFRC</td>
<td>Freeway system in and about Salt Lake City and Ogden Ares</td>
<td>Individual vehicle delay per mile (sec/mile)</td>
<td>Based on posted speed or functional class or roadway</td>
<td>System currently in development</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total vehicle delay per lane-mile (veh-min/lane-mile or min/mile)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern Nevada RTC</td>
<td>Freeway</td>
<td>In Development</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Portion of Las Vegas freeway system</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washington DOT</td>
<td>Statewide monitoring of major commuter routes</td>
<td>Vehicle hours per day per mile</td>
<td>Optimal flow speed (~51 mph)</td>
<td>Annual reports as part of the Gray Notebook. WSDOT does not distinguish between recurring and non-recurring delay in its congestion performance reporting.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vehicle hours per day per metro area</td>
<td>Posted Speed</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Statewide - daily and annual vehicle hours of delay</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annual cost of delay on state highways</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

In 2005, the National Transportation Operations Coalition (NTOC) identified and defined a set of key operations performance measures of national significance. This project furthered that effort by further refining their definitions, evaluating the issues associated with their use, and developing implementation guidelines. The measures, as refined from this project include:

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer Satisfaction</td>
<td>A qualitative measure of customers’ opinions related to the roadway management and operations services provided in a specified region.</td>
</tr>
<tr>
<td>Extent of Congestion – Spatial</td>
<td>Miles of roadway within a predefined area and time period for which average travel times are 30% longer than unconstrained travel times.</td>
</tr>
<tr>
<td>Extent of Congestion – Temporal</td>
<td>The time duration during which more than 20% of the roadway sections in a predefined area are congested as defined by the “Extent of Congestion – Spatial” performance measure.</td>
</tr>
<tr>
<td>Incident Duration</td>
<td>The time elapsed from the notification of an incident until all evidence of the incident has been removed from the incident scene.</td>
</tr>
<tr>
<td>Recurring Delay</td>
<td>Vehicle delays that are repeatable for the current time-of-day, day-of-week, and day-type.</td>
</tr>
<tr>
<td>Speed</td>
<td>The average speed of vehicles measured in a single lane, for a single direction of flow, at a specific location on a roadway</td>
</tr>
<tr>
<td>Throughput – Person</td>
<td>Number of persons including vehicle occupants, pedestrians, and bicyclists traversing a roadway section in one direction per unit time. May also be the number of persons traversing a screen line in one direction per unit time</td>
</tr>
<tr>
<td>Throughput – Vehicle</td>
<td>Number of vehicles traversing a roadway section in one direction per unit time. May also be the number of vehicles traversing a screen line in one direction per unit time</td>
</tr>
<tr>
<td>Travel Time – Facility</td>
<td>The average time required to traverse a section of roadway or other facility in a single direction.</td>
</tr>
<tr>
<td>Travel Time – Reliability</td>
<td>The Buffer Time is the additional time that must be added to a trip to ensure that travelers will arrive at their destination at, or before, the intended time 95% of the time.</td>
</tr>
<tr>
<td>Travel Time – Trip</td>
<td>The average time required to travel from an origin to a destination on a trip that might include multiple modes of travel.</td>
</tr>
</tbody>
</table>

Input from transportation professionals and the results of pilot tests contributed by over a dozen organizations helped refine the measures and provide information to characterize technical challenges, cost, and methods of reporting, as captured in the attached implementation guide. The reader is referred to the appendices for complete definitions and implementation guidelines. Conclusions from the activities of this project are summarized by performance measure below:
**Customer Satisfaction:** This performance measure is widely practiced and well established as evidenced from the pilot test results. The implementation guide summarizes existing best-practice, characterizes cost, and references additional resources available to assist organizations implementing such measures. The refined measure and associated guidelines emphasize the processes required to develop and administer a quality customer satisfaction survey.

**Incident Duration:** As with Customer Satisfaction, several positive case studies are available from which to obtain guidance on the collection, processing and display of Incident Duration measures. The implementation guide summarizes existing best-practice, identifies critical issues, and references additional resources. Costs for implementing Incident Duration measures are embedded in the system cost of for incident management systems.

The remaining measures, referred to collectively as Traffic Flow measures, are all derived from measurements of speed, travel-time and/or volume. The primary focus of the implementation guidelines is assistance navigating this matrix of methods and technology for collecting the speed, travel-time, and/or volume data needed for the computation of each of these measures. Data collection issues remain the primary challenge to implementing traffic flow performance measures. Freeway operations can be monitored using a variety of old and new technology, and either fixed sensors or new probe technologies. The nature of arterials requires floating car or vehicle probe methods in order to obtain travel time estimates.

**Travel Time – Facility:** Travel time is the primary and dominant traffic flow measure in use. Its ease of application and inherent understanding by the traveling public provides the greatest benefit for application and reporting purposes. Travel time serves as the basis for delay and reliability measures as well as effectively and easily communicates system status to the public using simple reporting mechanisms.

**Travel Time – Trip:** This measure was included in the NTOC set to reflect overall, multi-modal trip efficiency. Technology is not readily available to monitor end-to-end trip travel times on anything except special study purposes.

**Throughput – Vehicle:** The data collection, processing and reporting issues are well known and efficiently managed judging from the pilot test results. These measures have a long history of use originating from planning applications.

**Throughput – Person:** This is typically instituted by factoring vehicle throughput rates with occupancy factors obtained from periodic occupancy surveys. This measure is frequently used to assess performance of High Occupancy Vehicle (HOV) lanes.
**Delay – Recurring:** Vehicle delay is frequently used to ascribe a monetary value (or penalty) for the adverse effects of congestion. Any delay calculation is contingent upon establishing an unconstrained travel time appropriate to the area of study. Unconstrained travel times are determined specific to the region and facility, and methods to determine unconstrained travel time differ for freeways and arterials.

**Travel Time – Reliability:** Although relatively new, the implementation of the reliability measures (as per the NTOC definition) has quickly proliferated and has been consistently implemented. As a consequence, reliability measures are expected to grow in use and importance in determining funding and policy.

**Extent of Congestion – Spatial and Temporal:** Experimental implementation of the NTOC measure by at least three institutions had mixed results. Technical issues aside, it is unclear if the NTOC defined measures effectively capture and convey congestion information in time and space. Continuous monitoring of research work in this area, as well as continued experimentation with the defined measure, is recommended.

**Delay – Non-recurring:** No examples of non-recurring delay were submitted as part of the pilot tests, although some data submitted for incident duration could be construed as such. Although a clear concept, direct measures of non-recurring delay have not emerged as effective performance measures. The project concludes that non-recurring delay should be omitted from the list of core operations performance measures.

The NTOC measures as refined in this study and the associated implementation guidelines will assist organizations seeking to develop effective operations performance measures programs based on nationally acknowledged data collection methods, compilation procedures, and reporting mechanisms. Multiple positive case studies exist for the majority of the measures from which organizations can acquire templates and lessons-learned in order to affect their own efficient implementation. Moving forward, as additional experience is gained with emerging traffic flow technologies and methods, the material in the guidelines should be augmented with the knowledge from the most recent deployments. Likewise, knowledge and methods to effectively characterize and communicate extent of congestion measures will continue to develop and should serve to augment the guidance conveyed herein.

The project identified two areas for continued applied research. The first is in assisting organizations as they specify and procure appropriate traffic flow detection resources in light of the growing variety of technology options. The pressure to reduce costs by consolidating data collection efforts, while at the same time expanding coverage, will force many agencies to consider new methods and technologies. The implementation guidelines provided herein, as well as other resources cited, provide assistance navigating the current matrix of choices. This will require periodic updating as experience with the various systems proliferates. The second area for continued work is appropriate application of performance measures for signalized arterials. Concepts and measures originating from freeway operations may not as be immediately applicable, or the most appropriate measures in arterial environments. Although the base
measures of travel time and throughput apply, developing standard benchmarks will continue to be a challenge.
REFERENCES

