GUIDE TO BENCHMARKING OPERATIONS PERFORMANCE MEASURES

PRELIMINARY DRAFT
FINAL REPORT

Prepared for
NCHRP
Transportation Research Board
of
The National Academies

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Florida DOT
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Georgia Regional Transportation Authority
Inrix Inc.
International City/County Management Association (ICMA)
Institute of Transportation Engineers (ITE)
Maricopa Assoication of Government (MAG)
Maryland State Highway Administration
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Missouri DOT, Kansas City Scout
North Jersey Transportation Planning Authority
Regional Transportation Commission of Southern Nevada
Texas A&M
Traffic.com
Transportation Research Board (TRB)
Utah DOT
Virginia DOT
Volpe National Transportation Systems Center
Wasatch Front Regional Council
Washington DOT

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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 loose 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>
<tr><th></th><th colspan="4">Types of Applications</th></tr>
<tr><th rowspan="2">Performance Measure</th><th rowspan="2">Traffic Engineering</th><th rowspan="2">Transportation Planning</th><th colspan="2">Operations</th></tr>
<tr><th>Traffic Management</th><th>Traveler Information</th></tr>
<tr><td>Customer Satisfaction</td><td rowspan="2">5% - 10%</td><td rowspan="2">5% - 20%</td><td></td><td rowspan="4"></td></tr>
<tr><td>Incident Duration</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 rowspan="3">1% - 5%</td><td rowspan="3">2% - 10%</td><td rowspan="3">5% - 10%[a][b]</td><td rowspan="3">5% - 20%[a]</td></tr>
<tr><td>Travel Time - Facility</td></tr>
<tr><td>Travel Time - Trip</td></tr>
<tr><td>Travel Time - Reliability</td><td rowspan="3">5% - 10%</td><td rowspan="3">5% - 15%</td><td rowspan="3">5% - 10%</td><td rowspan="3">10% - 20%</td></tr>
<tr><td>Recurring & Non-Recurring Delay</td></tr>
<tr><td>Extent of Congestion Spatial & Temporal</td></tr>
</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>
<tr><th>Performance Measure</th><th>Base Data / Record</th><th>Measurement Methods</th><th>Primary Issue/s</th></tr>
<tr><td>Customer Satisfaction</td><td>Survey Response</td><td>Constituent Survey</td><td>Complexity of Survey</td></tr>
<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 rowspan="7">Estimate of Travel Time</td><td rowspan="7">Inference from Speed Sensors
Floating Car Methods
Vehicle Probe Methods</td><td rowspan="7">QCQA of Sensors
Density of Sensors
Sensor Outages
Conversion of Speed to Travel Time
Density of Probes</td></tr>
<tr><td>Travel Time - Trip</td></tr>
<tr><td>Travel Time - Reliability</td></tr>
<tr><td>Recurring Delay</td></tr>
<tr><td>Non-Recurring Delay</td></tr>
<tr><td>Extent of Congestion - Spatial</td></tr>
<tr><td>Extent of Congestion - Temporal</td></tr>
</table>

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.

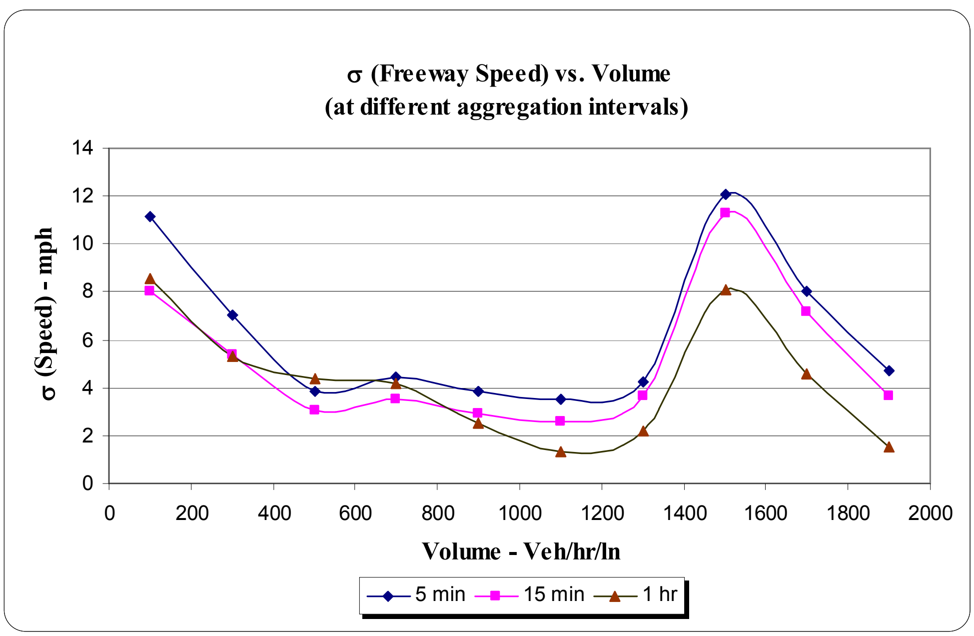

Figure 1. Standard deviation of freeway speed at 5 minute, 15 minute, and 1 hour volume aggregation summary levels.

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.

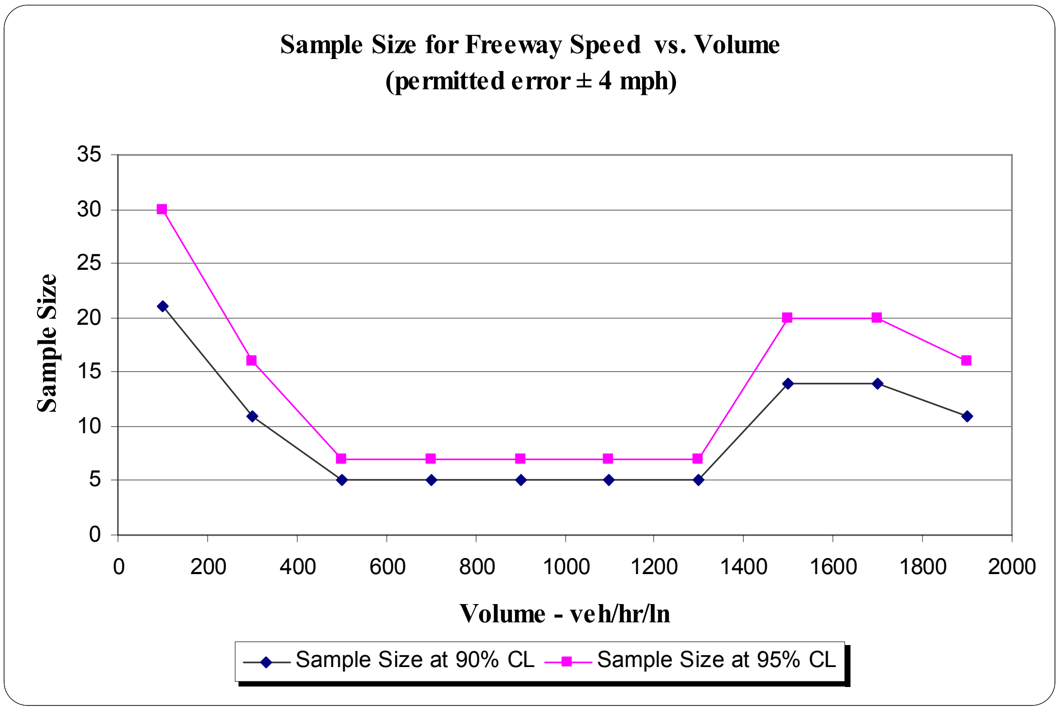

Figure 2. Minimum samples sizes for freeway speed detection. Chart depicts number of samples needed to obtain ±4 mph accuracy with 90% and 95% confidence based on observed sample standard deviation for various levels of per lane hourly volume.

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.

TABLE 3 Pilot Test Participants and Measures Tested

		Customer Satisfaction	Travel Time - Facility	Travel Time - Trip	Travel Time - Reliablity	Delay - Recurring	Delay - Nonrecurring	Speed	Extent of Congestion - Spatial	Extent of Congestion - Temporal	Throughput - Vehicle	Throughput - Person	Incident Duration
	Organization	1	2	3	4	5	6	7	8	9	10	11	12
1	Baltimore Metropolitan Council	x											
2	City of Overland Park, Kansas	x	x										x
3	Colorado DOT		x			x			x		x		
3	Florida DOT - District 4	x	x			x	x	x	x	x	x		x
4	Florida DOT - Distrct 5		x		x				x	x			
5	Georgia Regional Transportation Authority (GRTA)		x		x								
6	Maricopa Assoication of Government (MAG)		x		x			x	x	x	x	x	
7	Maryland SHA												
8	MetroPlan Orlando	x											
9	Maryland SHA		x					x					x
10	Southern Nevada RTC		x		x	x			x	x	x		
11	Virginia DOT	x	x					x	x	x	x		x
12	Wasatch Front Regional Council		x			x		x			x		
13	Washington DOT		x		x			x	x	x	x	x	x

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

	Customer Satisfaction Survey										
	Purpose of Survey	Survey Mechanism	Type of Operations and IT Services Surveyed	Engaged Professional Assistance	Number of Total Questions	Sample Size	Confidence Level / Error	Cost	Geographic Extents	Date	Survey Frequency
Balimore Metropolitan Council	Identify regional mobility interests and develop collaborative strategies to improve the quality of transportation and economic vitality throughout the Baltimore region.	Telephone	Extent of Congestion Traffic Signal Operations Transportation Information	Yes	30	1003	95% / 3.1%	-	Five counties & Baltimore City	May - June 2006	-
Florida DOT - District 4	Explore usage of, attitudes toward, and perceptions of Florida DOT's intelligent transportation system (ITS) services.	Telephone	DMS 511 Road Rangers Radio Traffic Reports TV Traffic Reports Web Site	Yes	31	400	3.90%	-	Florida District 4	March 2006	-
MetroPlan Orlando	Monitor the state of public thinking about transportation issues in the Orlando metropolitan area.	Telephone	Congestion Management Incident Management DMS Signal Coordination Travel Time Travel Time Reliability	Yes	76	840	-	-	Orlando metro area, 3 counties	Feb - Mar 2005	Previous surveys in 2001 & 2003
Overland Park, KS	The intent of the survey was to see if additional DMS on arterial streets would be seen as a positive feature by residents..	Mail and Telephone	DMS	Yes	22	527	95% / 4.5%	$7500 + 40 hours of staff time	City of Overland Park, KS	Jan - Feb 2007	One time survey
Virginia DOT	Develop and report regularly key measures of resident satisfaction for VDOT's functional and operational areas	Telephone	Traffic Management Incident Response 511 Phone and Web CMS	Yes	44	1800	-	$ 51,200	Statewide	May 2007	Periodic (Every 2-3 Years)

TABLE 5 Types of Questions Used in Customer Satisfaction Surveys

	Customer Satisfaction Questions						
	Nature of Questions				Question Structure		Sample Questions
		Assessment of					
	Type of Service	Frequency of Use	Satisfaction and/or Importance	Behavior Modification	Ordinal Scale « OS Yes or No « YN	Typical number of values for ordinal scale	
Balimore Metropolitan Council	Extent of Congestion Traffic Signal Operations Transportation Information	✓ · ·	✓ ✓ ✓	✓ · ·	OS / YN OS OS	5	Q18 How often have you experienced congestion on your way to or from work/school? Would you say ... ? [Always | Sometimes | Rarely | Never | Don't Know or Refused] Q20. Do you change your commute to work/school in any way as a result of congestion? [
Florida DOT « District 4	DMS 511 Road Rangers Radio Traffic Reports TV Traffic Reports Web Site	✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓	✓ ✓ · · · ·	YN / OS YN / OS YN / OS OS OS YN / OS	3 or 4	How often do you use the 511 service? [Frequently | Occasionally | Seldom | Never] Have you every been assisted by a Road Ranger unit? [P | No]
MetroPlan Orlando	Congestion Management Incident Management DMS Signal Coordination Travel Time Travel Time Reliability	✓ · · · · ·	✓ ✓ ✓ ✓ ✓ ✓	✓ · · · · ·	YN / OS OS OS OS OS OS	4	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. Clear highway accidents more quickly. Provide traffic information through hig
Overland Park, KS	DMS	✓	✓	✓	YN / OS	4 or 5	Q8. What do you think of the messages on these signs? Do you think they are: [Very easy to understand | Easy to understand | Neutral | Hard to understand | Very hard to understand | Don't know] Q10. Have you changed your route as a result of a messag
Virginia DOT	Traffic Management Incident Response 511 Phone and Web DMS	· · ✓ ·	✓ ✓ ✓ ✓	· · ✓ ·	OS OS YN / OS YN	5	Q21: Prior to this interview, had you ever heard of or read about 511, 511 Virginia, or 511 Virginia.org? [P | No] Q25b: What prompted you to use 511? [Traffic | Word of Mouth | Highway Sign | Advertisement | Weather | Trip Planning | Web Link | Don't

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 6 Summary of Incident Duration Pilot Test Data

Incident Duration										
Agency	**Program History**	**Incident Duration Definition**		Type and Frequency of Reporting	Duration Reported by:					NOTES
		Start Time	**End Time**		# of Lanes Blocked	Incident Type	Major Routes	Mean Duration	Median Duration	
Florida DOT - District 4	**Since 2005**	The time when the first agency is notified	The time when all evidence of the incident is removed from travel and shoulder lanes	Reports are generated weekly and published on the SunGuide web interface (www.smartguide.com)	✓	✓	✓	✓		Tracks and reports number of incidents by individual Road Ranger units. Detailed reporting by time of day, event type, severity, and roadway
Washington DOT	**Since 2002**	The time that WSDOT learns of the event	Two Distinct Durations are Reported WSDOT External: When the last responder has left the scene 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	Quarterly reports are generated and published through the gray notebook	✓	✓	✓	✓		Incident duration measures used in statewide GMAP performance management program. Goal is a 5% reduction in incident duration for incident > 90 minutes.
Virginia DOT	???	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.		Results are published monthly in the systems operations performance report. Some stats are available through the VDOT Dashboard	✓	✓	✓	✓	✓	Various incident management systems are used in different districts. All report data to a central system (called VOIS) from which incident duration is reported, but detail is lost in the process.
Maryland CHART	**Since 1997**	Incident open time (operator begins to input information)	Incident closed time (scene cleared time)	Yearly report focuses on evaluation and benefit of CHART operations Standard and adhoc reports available on-demand through RITIS	✓	✓	✓	✓		Tracks incident response with and without SHA Patrol assistance Quality of data with system is assessed annually as well

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.

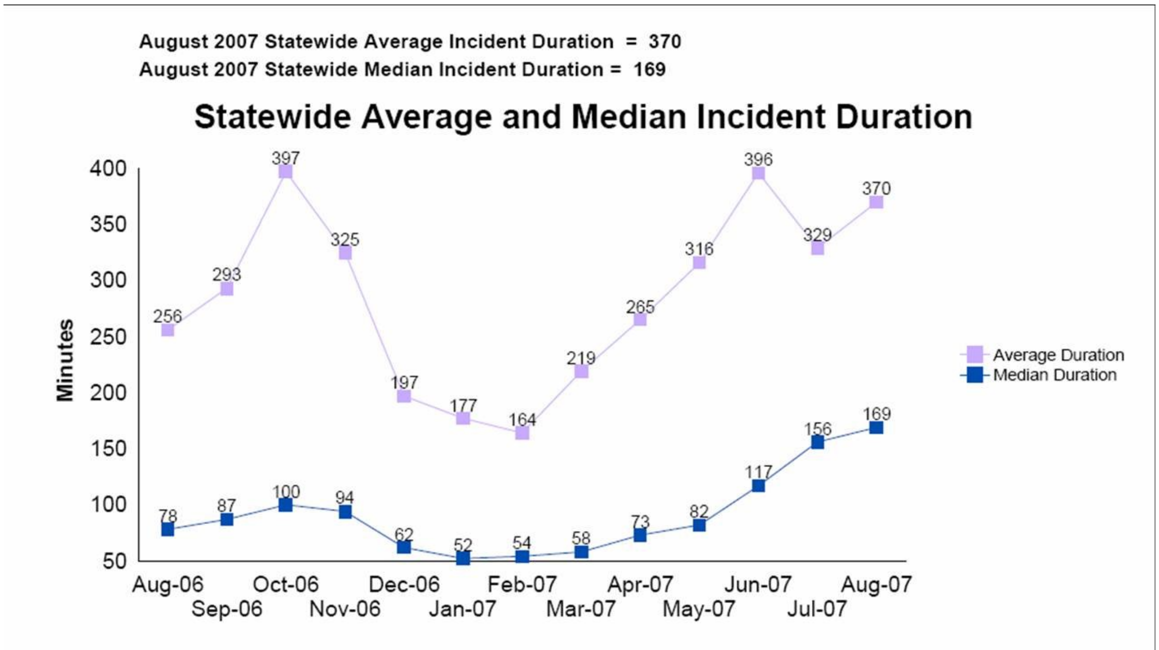

Figure 3. Mean versus Median Incident Duration. SOURCE: August 2007 Virginia System Operations Performance Report

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. 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 information is available at the FHWA Traffic Incident Management Program website at http://www.ops.fhwa.dot.gov/incidentmgmt/index.htm.

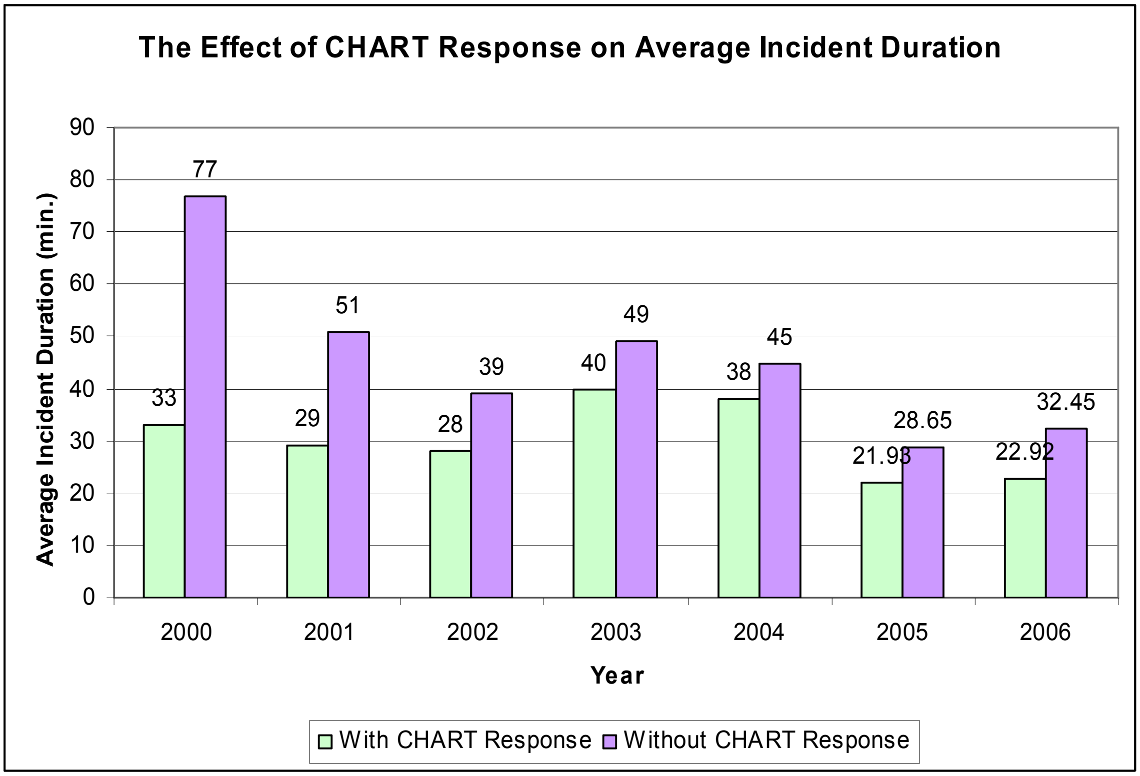

Figure 4. Impact of Response Vehicle on Incident Duration. SOURCE: Compiled from University of Maryland's 2006 Performance Evaluation of the Maryland State Highway Administration incident management system.

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 spread sheet 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 7 Summary of Data Collection for Traffic Flow Performance Measures

Volume, Occupancy, Speed, and Travel Time Data Collection													
						Performance Measures Assessed							
Agency	Type of Facilities	Data Collection Method or Technology	Extent of Data Collectoin / Study Area	History of Data Collection	Sampling Parameters	Speed	Travel Timie	TT - Reliability	Recurring Delay	Non-Recurring Delay	Extent of Congestion	Throughput	Notes
Colorado DOT	Commuter & Recreational Corridors	Floating car	68 corridors (Length: 1 - 54 mi)	Since 2000 on some corridors	8 runs for each period		✓		✓		✓	✓	Data collection for 2007 estimated at $318,000.
Florida DOT District 4	Freeway	Fixed Sensors Side-fire Radar	Two interstate corridors ~40 miles in lenth, I95 & I 595	Initiated 2007	Data is polled every 20 seconds	✓	✓					✓	Initial applications will be color coded maps and travel time on signs
Florida DOT District 5	Arterial	Probe vehicle Toll Tag Transponders	135 mile arterial network, representing 74 corridors	Initiated 2007	Travel time from matched toll tags each minute		✓				✓		---
Georgia Regional Transportatoin Authority (GRTA)	Freeway	Fixed Sensors: Video Based	16 birectional corridors (Length: 4 - 15 mi)	Reported since 2002	Aggregated to 15 minute intervals		✓	✓					Primary technical challenge was a calculation algorithm to account for high degree of sensor outages
Maricopa Assoication of Government (MAG)	Freeway	Fixed Sensors: Passive Accoustic Detectors & Loops	6 corridors (Length: 8 - 10 mi)	Since 2000	Reported in 15 minute intervals	✓	✓	✓			✓	✓	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
Maryland SHA	Freeway	Fixed Sensors: Side Fire Radar	70 Detectors throughout the Baltimore - DC area	Since 2002	5 minutes	✓	✓						Data quality control issues prevents use of sensor data for performance measures
Overland Park, KS	Arterial	Floating car	25 corridors (Length: 0.25 - 3 mi)	1994 to 2007	10 runs per direction		✓						Data collection requires 150 hours of staff time yearly
Southern Nevada Regional Transportaton Commission	Freeway	Fixed Sensors: Side Fire Radar & Loop Detectors	8 centerline miles on I-15 in Las Vegas between I-215 at the south and US 95 at the north	Since Sept 2006	Aggregated to 15 minute intervals		✓	✓	✓		✓	✓	Data sets and procedures from the pilot test are intended to be used as a functional sample for future production implemenation.
Virginia DOT	Freeway	Fixed Sensors: Dual Loops	Statewide monitoring from 216 permanent count stations	Archive available since 2003	Polled every 15 minutes	✓						✓	Costs for permanent count stations are available
		Fixed Sensors: Loop	6 corridors on I66 in Northern VA (Length: 7 - 11 miles each)				✓				✓		---
Wasatch Regional Front Council (WFRC)	Freeway	Fixed Sensors	---	---	Continuous	✓	✓		✓			✓	Utah DOT is currently implementing new analysis software. WFRC provided sample calculations of recommended/intended measures
Washington DOT	Freeway	Fixed Sensors: Loop Detectors ~4000 Single Loops & 100 Dual Loops	52 commutes in the central Peuget Sound region (Length: 7 - 25 mi)	At least since 2002	Polled every 20 seconds, aggregated to 5 minutes	✓	✓	✓	✓		✓	✓	WSDOT uses an extensive quality control plan for maintenance, calibration, and error checking developed by University of Washington TRAC.

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

Contrast of Data Collection Methods														
Method	Sub-Method	Base Measurements	Typcial Sampling Paragmeters	Freeway Use	Arterial Use	Performance Measures Supported: Speed	Travel Timie	TT - Reliability	Recurring Delay	Non-Recurring Delay	Extent of Congestion	Throughput	Costs	Primary Deployment Issues
Fixed Sensor	Single Loops	Volume & Occupancy	5 Minute	✓		X	X	X	X	X	X	X	$7500 to $20000 per site depending on availability of existing structures	Costs, Sensor Density, Maintenance, Quality Control
	Dual Loops	Volume, Occupancy, & Speed	5 Minute	✓		X	X	X	X	X	X	X		
	Cross-Fire Radar	Volume, Occupancy, & possibly Speed	5 Minute	✓		X	X	X	X	X	X	X		
	Video Cameras	Volume, Occupancy & Possibly Speed	5 Minute	✓		X	X	X	X	X	X	X		
Floating Car	GPS Instrumented	Travel Time	8-10 Runs per year, per corridor	✓	✓	X	X		X		X		Budget $300 to $500 per mile	Minimum Sampling Parameters
Vehicle Probe	Toll-Tag Transponder	Travel Time	1-5 minute	✓	✓	X	X	X	X	X	X		$15000 per site per direction (exclusive of structures)	Density of Toll-Tags and Cost of Equipment
	Fleet GPS Data		5 - 15 minutes	✓	?	X	X	X	X	X	X		$500 - $1000 / mile / year	Data Latency and Sampling Density
	Cell Phone Probes		1-10 minutes	✓	?	X	X	X	X	X	X		$500 - $1000 / mile / year	Accuracy, Privacy, and Business Model Sustainability

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 tot 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

Fixed Sensor Spacing		
Agency	**Sensor Spacing**	**Data Collection Method or Technology**
Florida DOT District 4	1/2 mile	Side-fire Radar
Georgia Regional Transportatoin Authority	1/3 mile	Video Based
Maricopa Assoication of Government	2-3 miles	Passive Accoustic Detectors & Loops
Maryland SHA	1.5 to 3 miles	Side-fire Radar
Southern Nevada RTC	1/3 mile	Side-fire Radar & Loop Detectors
Washington DOT	1/2 mile	Loop Detectors

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 Park, 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

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

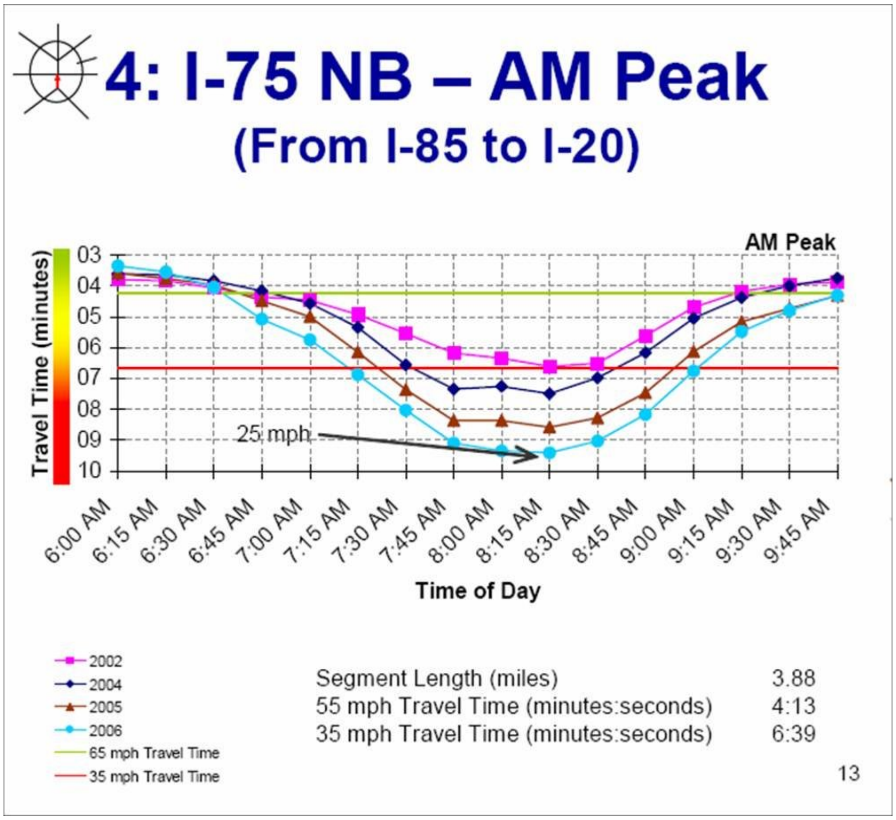

Figure 5. Sample Travel Time Illustration. SOURCE: Transportation MAP report published annually by Georgia Regional Transportation Authority.

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

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

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 12 Pilot Test Results for Throughput-Vehicle and Throughput-Person

Throughput - Vehicle & Person							
Agency	Vehicle			Person			
	Extent	Utility	Cost	Extent	Occupancy Factors	Utility	Cost
Colorado DOT	72 hour counts using tube/radar in conjunction with the floating car runs for 68 corridors (urban, commuter, & recreational)	Included in the corridor report and necessary for delay calculations	Included in the floating car data collectoin contract of ~$318K				
Maricopa Assoication of Government	Same network and exent as other measures, 26 locations on 6 selected corridors	Annual mobility report, calibrating/validating travel demand forecasting model	---	Same network and exent as other measures, 26 locations on 6 selected corridors	Manually collected vehicle occupancy data on each freeway detector location in 2006 - 2007.	Data has been reported on the MAG annual freeway mobility report, MAG regional traffic counts database and HPMS database.	---
Southern Nevada RTC	~ 8 mile portion of freeway network in LasVegas, NV	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.	---				
Virginia DOT	Statewide, 216 dual loop count stations	Used in conjunction with speed index to assess system's performance. Develop factors to create AADT and VMT estimates	---				
Washington DOT	Data is currently collected on most major freeways in the Puget Sound Region at approximately ½ mile intervals.	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.	Vehicle volume processing is a negligible percentage of the overall regional loop data collection system budget. This analysis is conducted annually as part of WSDOT's Performance Measurement work and consists of staff analysis time.	Selected locations are monitored each year throughout the Puget Sound region freeway network, on I-5, I-405, I-90, SR520, and SR167. Data are collected from both HOV and GP lanes	Based on up to thirty 30-minute peak period field counts per unique location/ travel direction /lane type during the Spring and Summer. Transit/vanpool ridership are based on all peak period ridership data from one transit service provider.	Three annual reporting mechanisms: (1) Gray Notebook external performance reporting document (2) a Seattle-area HOV lane system evaluation report (3) a Seattle-area freeway usage and performance monitoring report Person throughput estimates are also used by WSDOT to support a variety of HOV analyses, and as part of white papers and brochures.	$176K/year for occupancy data $6K/year for analysis and reporting

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 13 Pilot Test Results for Extent of Congestion – Spatial and Temporal

Extent of Congestion - Spatial & Temporal							
Agency	**Facility Type**	**Spatial**	**Temporal**	Description of Data Set	Definition of Unconstrained Travel Time	Congestion Threshold	Reporting
Colorado DOT	Arterial & Freeway	✓		As part of the 2007 report, spatial extent of congestion during peak periods will be calculated			
Florida District 5	Arterial 135 miles of arterial centerline data	✓	✓	135 Centerline Miles of arterials in the Orlando metropolitan area. 2006 travel times from automated toll-tag technology are used to estimate extent of congestin measures	1.3 times the travel time at posted speed	30% Greater than unconstrained travel time	Experimental Results
Maricopa Assoication of Government (MAG)	Freeway 6 major commuter corridors	✓	✓	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	Results have been used in the MAG annual freeway mobility report. However, the previous congestion definition was based on speeds, using “speed<=35 mph and speed<=50 mph” as the thresholds for severe congestion and congestion respectively.
Southern Nevada RTC	Freeway Portion of LasVegas freeway system	✓	✓	In Development, to be reported as part of the RTC-FAST system			
Virginia DOT	Freeway I66 in Northern Virginia	✓	✓	In Development, to be reported on the VDOT Dashboard			
Washington DOT	Freeway 44 Mile Section of I5 passing through Seattle	✓	✓	Extent of congestion was assessed on I5 using data sets from 2004 and 2006 for comparison and contrast	Posted Speed	70% of Posted Speed	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.

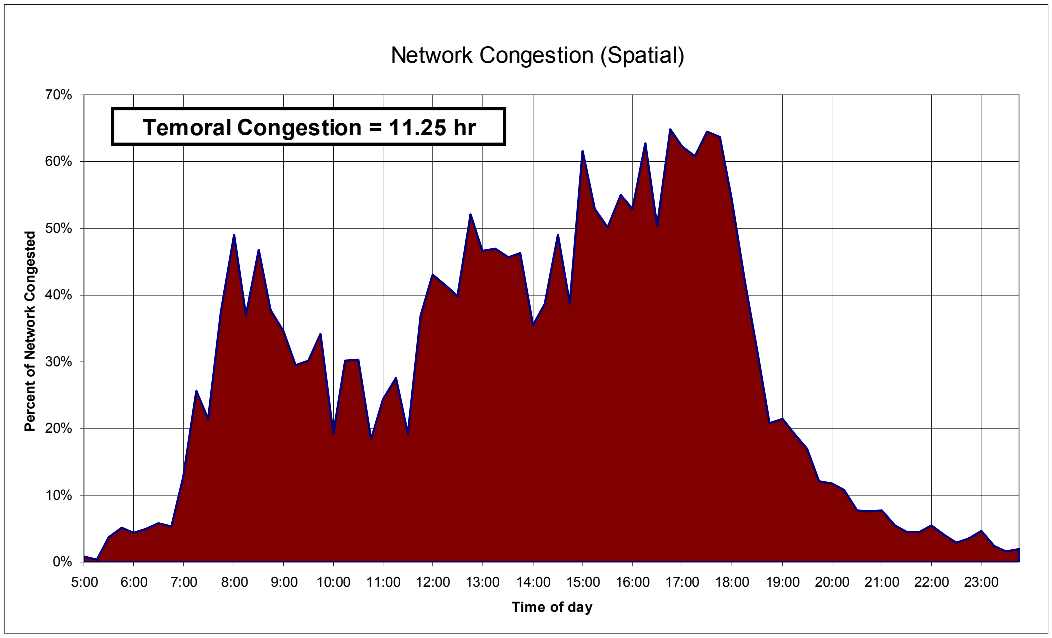

Figure 6. Temporal Extent of Congestion on an Arterial Network. Unconstrained travel time determined as 30% greater than the speed limit equivalent travel time. SOURCE: Data obtained from Florida DOT District5

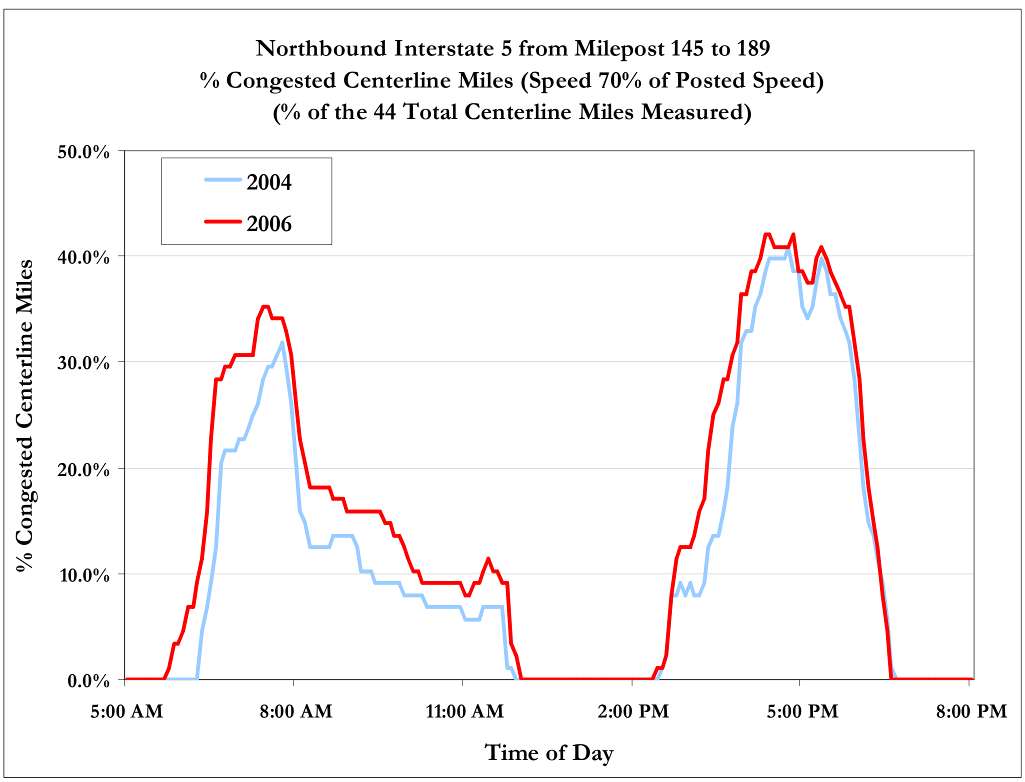

Figure 7. Spatial Extent of Congestion Based on 30% Reduction in Speed. SOURCE: Contributed by Washington DOT during pilot test.

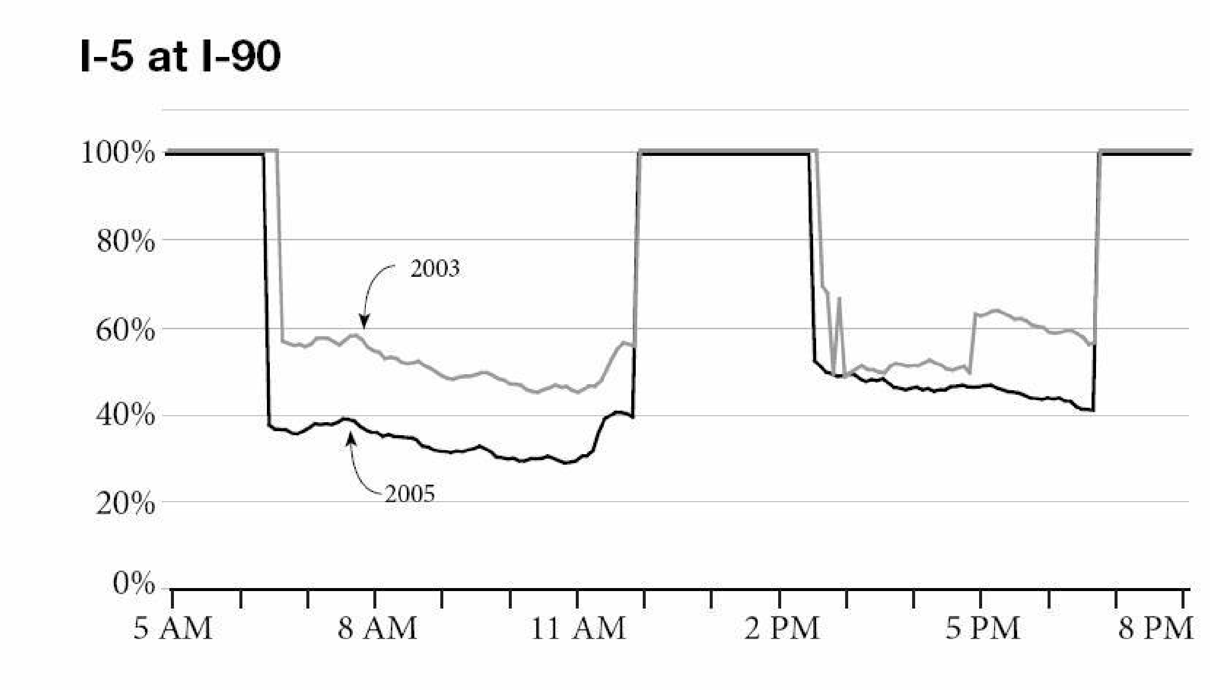

Figure 8. Loss of Productivity congestion measure based on throughput data. SOURCE: Washington DOT Gray Notebook Sept 30, 2006.

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

Travel Time Reliability								
Agency	Type of Facilities	Reporting Frequency & History	Periods of Reporting	Unit of Measure Reported			Reporting Costs	Notes
				95% Travel Time	Planning Time Index (PTI)	Buffer Time Index (BTI)		
Georgia Regional Transportatoin Authority	16 major freeway commuting corridors in the Atlanta metropolitan area	Annual Report since 2002, available on the internet	15 minute intervals during peak periods: 6 AM -10 AM and 3 PM - 7 PM			✓	$12,000 consulting fees plus an additional 80 staff hours annually for all measures	
Maricopa Assoication of Government	6 heavy volume freeway commuter corridors in the Phoenix metro area	Annual Congestion Report	15 minute intervals during peak periods: 5 AM - 10 AM and 2 PM - 7 PM	✓	✓		62 staff hours annually (all measures)	Included asa standard measure in travel time reporting
Southern Nevada RTC	Portion of freeway network in LasVegas, NV	In Development, sample calculation from pilot study will servce a functional sample for later production.					---	
Washington DOT	Freeway communting routes, 52 in the Puget Sound area, and two in Spokane	Annual report and also on its interactive "Calculate Your Commute" website.	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.	✓			---	Reports reliability stats only on commutes experiencing congestion, 38 of the 52 routes in the 2007 report.

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

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

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:

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.
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.

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.

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