



# Monitoring Urban Freeways in 2003:

Current Conditions and Trends from  
Archived Operations Data

December 2004

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The Texas A&M University System  
College Station, Texas



Cambridge Systematics, Inc.  
Knoxville, Tennessee

Sponsored by



Federal Highway Administration  
U.S. Department of Transportation



## ***Final Report***

# ***MONITORING URBAN FREEWAYS IN 2003: CURRENT CONDITIONS AND TRENDS FROM ARCHIVED OPERATIONS DATA***

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16. Abstract  <p>The Mobility Monitoring Program is an effort by the Federal Highway Administration (FHWA) to track and report traffic congestion and travel reliability on a national scale. The Program uses archived traffic detector data that were originally collected for traffic operations purposes. The Program started in 2001 (with an analysis of 2000 data) in 10 cities. In 2004, the Program has grown to include nearly 30 cities with about 3,000 miles of freeway. The Program tracks three congestion measures (travel time index, percent congested travel, and delay) and two travel reliability measures (buffer index and planning time index).</p> <p>The findings from the most recent analysis of 2003 data are as follows: (1) Average traffic congestion and reliability from 2000 through 2003 appears to have experienced steady decline in numerous cities. (2) In most cities, travel reliability appears to be strongly correlated to traffic congestion. The nature of this relationship varies among cities, but preliminary hypotheses suggest that aggressive freeway operations and management contributes to improved reliability for similar average congestion levels. (3) The approach used in this Program can also be used by State and local agencies. In fact, several agencies already have implemented similar analytical methods and/or performance measures. (4) There are still several issues that, if addressed, could improve the process and results. One of the most important issues to address is improving data quality at the data collection source.</p>			
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8. Detroit: Michigan DOT
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## SUMMARY

### What is the Mobility Monitoring Program?

The Mobility Monitoring Program is an effort by the Federal Highway Administration (FHWA) to track and report traffic congestion and travel reliability on a national scale. The program has two primary objectives:

1. Monitor traffic congestion levels and travel reliability trends using archived traffic detector data; and
2. Provide “proof of concept” and technical assistance to encourage local/regional performance monitoring programs.

The Program uses archived traffic detector data that were originally collected for traffic operations purposes. Thus, the extent of the Program is limited to those cities and roadways where real-time traffic data are collected and archived. The Program started in 2001 (with an analysis of 2000 data) in 10 cities. In 2004, the Program has grown to include nearly 30 cities with about 3,000 miles of freeway. The Texas Transportation Institute and Cambridge Systematics, Inc. support the Mobility Monitoring Program activities.

### What performance measures are used?

The Program monitors traffic congestion using these measures:

- *Travel time index* – the ratio of average peak travel time to a free-flow travel time (in this report, the travel time at 60 mph for freeways). For example, a value of 1.20 means that average peak travel times are 20 percent longer than free-flow travel times.
- *Percent of congested travel* – the ratio of congested travel to total travel. The analysis uses vehicle-miles of travel (VMT); person-miles of travel could also be used if person flows are of interest and widely available. The percent of congested travel is a relative measure of the amount of travel affected by congestion.
- *Delay* – the additional travel time that is incurred when actual travel times are greater than free-flow travel times. The delay is expressed in several different ways, including total delay in vehicle-hours, total delay per 1,000 VMT, and share of delay by time period, day of week, or speed range.

The Program includes these measures for travel reliability:

- *Buffer index* – the extra time (buffer) most travelers add to their average travel time when planning trips. For example, a buffer index of 40 percent means that a traveler should budget an additional 8-minute buffer for a 20-minute average peak travel time to ensure on-time arrival most of the time (95 percent in this report).

- *Planning time index* – Statistically defined as the 95<sup>th</sup> percentile travel time index, this measure also represents the extra time most travelers add to a free-flow travel time when planning trips. For example, a planning time index of 1.60 means that travelers plan for an additional 60 percent travel time above the free-flow travel time to ensure on-time arrival most of the time (95 percent in this report).

The Program also tracks throughput (an “output” measure) using peak-period and total daily VMT.

### **What data are used?**

The Mobility Monitoring Program uses archived traffic detector data that were originally collected for traffic operations purposes. Thus, the extent of the Program is limited to those cities and roadways where real-time traffic data are collected and archived. This real-time traffic data is typically collected in those cities and roadways where traffic congestion is a daily problem. Nearly all of the data used in the Program are from freeways.

The archived traffic detector data is more detailed than data typically collected for traditional traffic congestion studies. Roadway or roadside sensors collect traffic volumes and speeds in every lane at ½-mile to 1-mile intervals. The real-time traffic data are typically sent from a field computer to a central database every 20 seconds to 1 minute; the data may later be aggregated into 5-minute summaries for permanent storage. The data typically are collected 24 hours each day, 365 days per year. The data are later grouped into several time periods for reporting, and most congestion and reliability measures are presented for peak traffic periods.

### **Where can I find more information or view city-specific reports?**

More information on the Mobility Monitoring Program can be found at <http://mobility.tamu.edu/mmp>. The Program has produced annual summary reports as well as city-specific reports since 2001, and the most recent reports are available at this website. In October 2004, the Program began producing monthly reports to provide more timely trend information to FHWA. These monthly reports are available on request.

### **What do we know after 4 years of monitoring traffic congestion and reliability?**

We offer the following observations:

- From 2000 through 2003, average traffic congestion and reliability levels appear to have gotten worse in numerous cities. The trend analysis is complicated by increasing freeway coverage. Additional analyses that accounted for increasing freeway coverage indicate the possibility of little significant change in the peak periods, with delay growth being more significant in the times and days outside of the defined peak period (weekdays, 6-9 a.m. and 4-7 p.m.).
- In most cities, travel reliability appears to be strongly correlated to traffic congestion. The nature of this relationship varies among cities, but preliminary hypotheses suggest that

aggressive freeway operations and management contributes to improved reliability for similar average congestion levels.

- The approach used in this Program can also be used by State and local agencies. In fact, several agencies already have implemented similar analytical methods and/or performance measures.
- There are still several issues that, if addressed, could improve the process and results. One of the most important issues to address is improving data quality at the data collection source.



# 1. INTRODUCTION

## Objectives of the Mobility Monitoring Program

The Mobility Monitoring Program is an effort by the Federal Highway Administration (FHWA) to track and report traffic congestion and travel reliability on a national scale. The program has two primary objectives:

1. Monitor traffic congestion levels and travel reliability trends using archived traffic detector data; and
2. Provide “proof of concept” and technical assistance to encourage local/regional performance monitoring programs.

The Program uses archived traffic detector data that were originally collected for traffic operations purposes. Thus, the extent of the Program is limited to those cities and roadways where real-time traffic data are collected and archived. The Program started in 2001 (with an analysis of 2000 data) in 10 cities. In 2004, the Program has grown to include nearly 30 cities with about 3,000 miles of freeway. The Texas Transportation Institute and Cambridge Systematics, Inc. support the Mobility Monitoring Program activities.

## Report Overview

This annual summary report provides the traffic congestion and reliability levels and trends from 2003, the most recent year of available data. The 2003 data were gathered from 29 cities in the United States. Congestion and reliability trends from three years (2001-2003) are available in 20 of these cities, and four years of trends (2000-2003) are available in 10 of these cities.

This report is organized as follows:

1. *Introduction* – brief overview of the Mobility Monitoring Program and the annual summary report;
2. *Background* – supplemental information on the Mobility Monitoring Program and other national/State performance monitoring programs;
3. *Data, Analysis Methods, and Performance Measures* – documentation of the data source, analysis methods, and resulting performance measures;
4. *Major Findings and Conclusions* – findings and conclusions based on analyses of 2000-2003 traffic congestion and reliability data; and
5. *Recommendations* – recommendations for improving the process and Program results.

## New Report Elements

Readers who are familiar with the Mobility Monitoring Program and its previous reports will recognize that many elements of our analysis and this report are similar to previous annual editions. There are, however, several new elements or changes that are noted:

- *Greater emphasis on multi-year trends* – Now that we have accumulated a minimum of three years of data for at least 20 cities, we have placed a greater emphasis in this report on traffic congestion and reliability trends from 2000 through 2003.
- *Less emphasis on city-specific information* – Because of differences in data collection, coverage, and quality for each city, past reports have warned against comparing traffic congestion or reliability levels between cities. In keeping with this principle, we have provided less city-specific information and more national composite statistics.
- *More cities* – This annual report for 2003 data includes 29 cities; the annual report for 2002 data (FHWA-OP-04-011) included 23 cities, whereas the annual report for 2001 data (FHWA-OP-03-141) included 21 cities. The total freeway mileage included in these 29 cities for 2003 totals nearly 3,000 miles.
- *Format and layout changes to city reports* – The Mobility Monitoring Program produces city-specific reports (separate from this annual summary report) that are intended to provide useful information for State and local agencies. The content of these city reports has been streamlined to provide only the most relevant information. This includes a summary page, various charts that show day-of-week and time-of-day patterns, tables that show traffic congestion and reliability by freeway section, and information on data sources and data quality.

## Additional Information and City Reports

More information on the Mobility Monitoring Program can be found at <http://mobility.tamu.edu/mmp>. The Program has produced annual summary reports as well as city-specific reports since 2001, and the most recent reports are available at this website. In October 2004, the Program began producing monthly reports to provide more timely information to FHWA. These monthly reports are available on request.

City reports are intended to provide useful information for State and local agencies, and as such, are considered a benefit for agencies providing archived data. These city reports are separate from this annual summary report but can be downloaded from the Mobility Monitoring Program website at <http://mobility.tamu.edu/mmp>.

## 2. BACKGROUND

This chapter contains background information on the Mobility Monitoring Program, and compares and contrasts this Program with other national performance monitoring programs. This chapter also highlights several examples of state and local performance monitoring programs.

### National Performance Monitoring Programs

There are three programs at a national scale that attempt to measure city-level traffic congestion, and two of these three programs also track travel reliability. These programs are as follows:

- *Mobility Monitoring Program* – The main subject of this report, this program uses archived traffic detector data to monitor traffic congestion and travel reliability in nearly 30 cities. This program is sponsored by FHWA and supported by the Texas Transportation Institute and Cambridge Systematics, Inc.
- *Urban Congestion Reporting Program* – This program gathers current traveler information reports from websites, archives the data, and provides monthly reports on traffic congestion and reliability in about 10 cities.<sup>1</sup> This program is sponsored by FHWA and supported by Mitretek.
- *Urban Mobility Report* – This effort uses aggregate data from FHWA’s Highway Performance Monitoring System (HPMS) to produce an annual report on traffic congestion and its impacts (wasted time and fuel and their costs) in the 85 largest cities in the United States.<sup>2</sup> The study’s annual report is given extensive coverage in the media, and is sponsored by the American Road and Transportation Builders Association, the American Public Transportation Association, and the Texas Transportation Institute.

The following sections provide an overview of these programs. Various elements of these three activities are compared in Table 1.

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<sup>1</sup> Wunderlich, K., S. Jung, J. Larkin, and A. Toppen. *Urban Congestion Reporting (UCR) Methodology and Findings: Year 1*. Draft Report, December 2003.

<sup>2</sup> Schrank, D. and T. Lomax. *2004 Urban Mobility Report*. Texas Transportation Institute, September 2004, available at <http://mobility.tamu.edu/ums/>.

**Table 1. Key Features of National Performance Monitoring Programs**

Feature	National Performance Monitoring Program		
	Urban Mobility Report	Urban Congestion Report	Mobility Monitoring Program
Number of cities in 2004	85	10	30
Expected cities in 2005	85	About 15	About 35
Years available	1982 to current	2002 to current	2000 to current
Source of data	HPMS (AADT, number of lanes, ITS deployments)	Travel times from websites (combination of reported travel times and TMC data)	Archived direct measurements of speeds, volumes, and travel times
Reliability measured?	No	Yes	Yes
Events monitored?	No	Incidents and weather (work zones planned)	No, but weather and incident data planned
Geographic coverage of data	All roadways in urbanized area	Covered highways (mostly instrumented freeways)	Instrumented freeways
Temporal coverage of data	Annual averages	Weekday (from 5:30 a.m. to 8:30 p.m.)	Continuous (24 hours per day, 365 days per year)
Geographic reporting (analysis) scale	Areawide	Areawide	Areawide and directional routes
Temporal reporting (analysis) scale	Average annual and total statistics	Peak period	Weekend/weekday; peak and off-peak periods
Analysis timeframe	Annual	Monthly	Annual; monthly for some cities
Time lag for reporting	18 months	10 working days	15 days for monthly reports; 6-9 months for annual report

## *Mobility Monitoring Program*

The Mobility Monitoring Program (MMP) calculates route and system performance measures based on data collected and archived by traffic management centers. These data are detailed direct measurements from roadway-based sensors installed for operational purposes. Data from spot locations (volumes and speeds) are used as well as travel times from probe vehicles where available. For each participating city, the program team develops congestion and reliability statistics at both the directional route and areawide level. The Program started in 2001 (with an analysis of 2000 data) in 10 cities. In 2004, the Program has grown to include nearly 30 cities with about 3,000 miles of freeway.

The concepts, performance measures, and data analysis techniques developed and used in the MMP are being considered for adoption and implementation by several State and local agencies. A few of these agencies have contacted the project team to request technical assistance or additional detailed information on performance monitoring or operations data archiving. Specifically, one of the two primary objectives of the MMP was to provide incentives and technical assistance for the implementation of data archiving systems to support performance monitoring. Several examples of these technology transfer and implementation activities are:

- Data quality control procedures have been developed for archived traffic data. Many locally developed archives are now using these procedures.
- Customized local analyses have been performed on a selective basis. As a way to promote local use of the archived data, the MMP team has demonstrated how their data may be used to supplement traffic counting programs (Phoenix and Cincinnati) and as input to air quality models (Louisville and Detroit).
- A data warehouse of archived traffic data that has been checked for quality and put into a standard format is available for research and other FHWA purposes. For example, the data are being used now in FHWA's "Estimating the Transportation Contribution to Particulate Matter Pollution" project and is being considered as a validation source for FHWA's "Next Generation Traffic Simulation Models" project.

The MMP also reports data gathered through FHWA's Intelligent Transportation Infrastructure Program (ITIP). The ITIP is an ongoing program designed to enhance regional surveillance and traffic management capabilities in up to 21 metropolitan areas while developing an ability to measure operating performance and expanding traveler information through a public/private partnership involving the FHWA, participating State and local transportation agencies, and Mobility Technologies, Inc. Under this partnership, Mobility Technologies is responsible for deploying and maintaining traffic surveillance devices, and integrating data from these devices with existing traffic data to provide a source of consolidated real-time and archived data for the participating metropolitan areas. As of late 2004, deployment has been completed in Philadelphia, Pittsburgh, Chicago, Providence, and Tampa. Deployment is also under way in Boston, San Diego, Washington DC, Phoenix, Los Angeles, San Francisco, Detroit, St. Louis, and Oklahoma City. Negotiations are currently active in 7 additional cities.

Part of ITIP is the production of performance measures on a routine basis. The metrics used to report performance are based on those in the MMP: travel time index, buffer index, percent congested travel, and total delay. Performance measure reports are provided to the U.S. Department of Transportation (DOT) and FHWA on a monthly and annual basis, as well as being included in corresponding MMP reports. The monthly reports for each completed metropolitan area are based on monthly data and are presented with similar content and in a format consistent with the city reports that are part of the Mobility Monitoring Program.

### *Urban Congestion Reporting Program*

The Urban Congestion Reporting (UCR) Program is sponsored by FHWA to provide a monthly snapshot of roadway congestion in 10 urban areas using three national composite measures. UCR utilizes efficient, automated data collection procedures (colloquially known as “screen scraping” or “web mining”) to obtain travel time directly from traveler information web sites and archives them at five-minute intervals on the weekdays when these services are available. Since a monthly report can be rapidly constructed (within 10 working days), UCR serves as an early warning system for changes in urban roadway congestion. Concurrent with the travel time data collection, other UCR acquisition programs obtain web-based data on weather conditions and traffic incidents (work zone activity is planned). This allows the UCR monthly report to include not only congestion level, but a range of possible contributing factors. A one-page overview tells the congestion story each month in a graphical manner for the analyst or administrator wanting a timely composite overview of congestion trends on a month-to-month basis.

### *Urban Mobility Report*

The Urban Mobility Report (UMR) tracks congestion patterns in 85 of the largest metropolitan areas, with historical data dating back to 1982. The UMR has been instrumental as both a source of trend information and development of the concepts and metrics for congestion monitoring. For example, the widely used travel time index is a performance measure concept originating from the UMR. The UMR relies on the Highway Performance Monitoring System (HPMS) as its source of information. It uses the average annual daily traffic (AADT) and number of lanes data in HPMS as a basis for its estimates; these are then translated into congestion metrics using predictive equations that have been developed and tested specifically for the UMR. Beginning in 2002, the UMR is also considering the positive effects that operational strategies have on system performance; these are accounted for as adjustments to the base performance predicted by AADT and number of lanes. The UMR has widespread visibility both within the transportation profession as well as with the general public; annual release of the UMR generates a significant amount of media interest and coverage.

### *Comparison of Programs*

All three of these current national programs use data collected for other purposes. This is particularly true for the UCR and MMP, which use operations-based data. Not having to implement a special data collection program solely for performance monitoring is a powerful argument for FHWA to make – it shows that the agency is using its resources wisely. As indicated earlier in Table 1, the three performance monitoring programs use different data and

have slightly different outputs. The strengths and weaknesses of the three efforts may be summarized in the following paragraphs.

The UMR has the longest history available, provides a widely accepted benchmark for comparisons, and covers all major freeways and arterial streets in an area. Up until now, it has served as the basis for FHWA performance reporting to others in U.S. DOT. However, since it is based on transforming HPMS data (annual average daily traffic volumes and number of lanes) into congestion metrics, it provides only an indirect estimate of congestion at an areawide level and doesn't consider travel time reliability. Also because of its reliance on HPMS, there is a substantial lag in reporting (typically 18 months).

The UCR has been the timeliest of the three programs, providing monthly congestion and reliability statistics. However, it is likely that MMP will also be able to provide similar monthly reports for a greater number of cities (20 cities estimated by mid-2005). The UCR program provides a general assessment of events that influence congestion (incidents and weather, with work zones planned). Since it is based on whatever information is posted to websites, highways other than freeways can be included (although this coverage is now very limited). However, the UCR data sources (website-based travel times, sometimes self-reported by commuters) are limited to those highways covered by websites that offer travel time reports. Also, because traffic volumes are not available, total delay is not available and relative comparisons between cities can be misleading. Generally, the number and quality of traveler information services have been improving over time, but these external changes can have a significant effect on UCR congestion measures as a whole.

The MMP provides the most detailed picture of congestion (in terms of time and geographic scales reported as well as multiple reliability statistics and VMT-weighted results). It also serves as an outreach mechanism promoting the use of performance measures, quality control procedures, and archived data to State and local agencies. Recent improvements to automation have improved the reporting lag, and the program team has begun producing monthly reports for 10 cities, with plans to expand this to 20 cities by mid-2005.

#### *Other Related National Activities*

Additionally, there are two other efforts that also relate to national monitoring of traffic congestion and travel trends:

- *Highway bottleneck study* – In a 2004 report titled “Unclogging America’s Arteries,” the American Highway Users Alliance identified 233 highway bottlenecks where delay exceeded 700,000 annual hours of delay.<sup>3</sup> The report also provided an in-depth analysis of the worst 24 bottlenecks in the country, in which the delay for each of the bottlenecks was greater than 10 million hours annually. A previous edition of this report on highway bottlenecks was published in 1999.

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<sup>3</sup> Cambridge Systematics, Inc. *Unclogging America’s Arteries: Effective Relief for Highway Bottlenecks*. American Highway User’s Alliance, February 2004, available at <http://www.highways.org/>.

- *National Household Travel Survey (NHTS)* – The NHTS is a U.S. DOT effort sponsored by the Bureau of Transportation Statistics (BTS) and the FHWA to collect data on both long-distance and local travel by the American public.<sup>4</sup> The joint survey gathers trip-related data such as mode of transportation, duration, distance and purpose of trip.

The highway bottleneck study and the NHTS are mentioned here for completeness, but the results of these activities are not directly comparable with the three other programs mentioned earlier. The highway bottleneck study only considers specific locations and does not address areawide estimates of congestion, nor does it address annual trends. The NHTS relies on self-reporting of person trips, and as such, does not use the same methods of traffic data collection as employed in several of the congestion monitoring programs. For example, the NHTS reports average travel times to work (as reported by commuters) but does not report average speeds for these trips.

### **Examples of State and Local Programs**

There are numerous State and local performance monitoring programs that have similar objectives to the Mobility Monitoring Program, with the major difference being the geographic scale. In fact, several of these State and local performance monitoring programs use the same archived traffic data as is used in the Mobility Monitoring Program. This section briefly highlights several examples of these programs. Additional information and detailed case studies on State and local performance monitoring programs will be included in a forthcoming NCHRP report on freeway performance monitoring.<sup>5</sup>

#### *Atlanta, Georgia*

The Georgia DOT has developed an Operations Business Plan that is driving the implementation of performance measures at NaviGAator (<http://www.georgia-navigator.com/>), the regional traffic management center for Atlanta. Their Operations Business Plan follows the “vision-goals-objectives-performance measures-targets-actions” sequence for achieving change via a performance-based process.

The NaviGAator staff uses output measures for incident and staff efficiency to provide benefits information to GDOT management and to the public in a weekly newsletter format. The incident and traveler information data is published monthly and distributed to GDOT management staff and others. The staffing measures are used to measure personnel performance, to adjust staff size and hours and to better define the operators shift hours. The HERO (service patrol) drivers incident data is used to adjust individual patrol routes for the HERO drivers and to define the HERO divers need per shift.

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<sup>4</sup> See [http://www.bts.gov/programs/national\\_household\\_travel\\_survey/](http://www.bts.gov/programs/national_household_travel_survey/) for more information on the National Household Travel Survey.

<sup>5</sup> See NCHRP Project 3-68, “Guide to Effective Freeway Performance Measurement,” <http://www4.trb.org/trb/crp.nsf/All+Projects/NCHRP+3-68>.

Some of the output measures currently used by NaviGator include:

Outcome

- Hampered by data quality concerns. Currently experimenting with a two categories of congestion: Moderate (speeds between 30 and 45 mph) and severe (less than 30 mph). Considering additional performance measures including reliability.

Output

- Traveler Information Calls
  - Total calls
  - Calls per day
  - Calls per route
  - Calls by type of call
  - Average call length
  - Average answer time
- Incidents managed
  - By category
  - Detection method
  - Impact levels (general categories)
- Number of construction closures
- Device Functioning
- % time devices are available
- Number of media communications by outlet
- Website visits by type of information requested

*Minneapolis-St. Paul, Minnesota*

In an annual Departmental Results report, the Minnesota DOT (MnDOT) tracks a number of performance measures statewide. Performance measures have therefore become part of an institutional reporting process. Performance data also serve as a basis for Metro Council plans and reports such as the Regional Transportation Plan, the Transportation Improvement Plan, the annual update of the Transportation Systems Audit and various operations studies. Although performance measures generally are not linked directly to specific investments, the findings and recommendations of the plans ultimately play a part in influencing investment decisions.

The operations outcome measures of travel speed and its derivatives of travel time and reliability are just now being developed for use by the regional traffic center staff. The primary reason for the previous non-usage is data quality as described in the Data Quality section and the recent move to the new regional traffic center building. The regional traffic center staff uses the output measures for incident and staff efficiency to provide benefits information to MnDOT management and to the public. The incident data is published monthly by regional traffic center staff and distributed to MnDOT management staff. The staffing measures are used to measure personnel performance, to adjust staff size and hours and to better define the operators shift hours. The FIRST (i.e., incident response) drivers' incident data is used to adjust individual patrol routes for the FIRST drivers and to define the FIRST divers need per shift.

The operations agencies plan to track these performance measures:

- Average incident duration
- Percent of highway miles w/peak period speeds < 45mph
- Travel Time Index
- Travel times on selected segments, including mean, median, and 95th percentile

The planning agencies plan to track these performance measures:

- HOV usage
- Roadway congestion index
- Percent of daily travel in congestion
- Percent of congested lane-miles in the peak period
- Percent of congested person-miles of travel
- Annual hours of delay
- Change in citizen's time spent in delay
- Congestion impact on travel time
- Travel Time Index

### *Phoenix, Arizona*

The original impetus for performance monitoring in Phoenix was to support the Arizona DOT's Strategic Action Plan, which is performance-based. Performance measures are at the core of this effort. However, agencies are discovering uses for performance measures beyond fulfilling the requirements of the Strategic Action Plan.

Performance measures are used by the traffic management center staff for operations, emergency response and traveler information applications. Each measure is employed to achieve the objectives set forth in the Arizona DOT's Strategic Action Plan. The monitoring of speed and volume using archived traffic data allows center staff to measure the average percentage of Phoenix freeways reaching level of service "E" or "F" on weekdays to determine if the Group's objective of operating 60 percent of the freeways at a level "D" or better during rush hour is met. For freeway construction, performance measures are used in three ways. First, the measures help bolster priorities for freeways versus other transportation projects. They also provide justification of the one-half cent sales tax for construction of controlled-access highways. Lastly, they are used to prioritize implementation.

The operations agencies track these outcome performance measures:

- Speed
- Average % of freeways reaching LOS E or F on weekdays
- Traffic volumes/counts
- Vehicle occupancy

The planning agencies track these performance measures:

- Congestion Index (% of posted speed)
- Travel time
- Segment delay (seconds/mile)

- Stop delay (<3mph) (seconds/mile)
- Average speed (% of posted speed)
- Average speed (mph)
- Average HOV lane speed (mph)
- Running speed ((length/travel time)-stop delay)
- Total volume
- HOV lane volume
- General purpose lane volume
- % peak period truck volume
- % peak period volume
- Lane-mile operating at LOS F
- Hours operating at LOS F

### *Seattle, Washington*

A mandate from state legislature resulted in the annual performance report known as Measures, Markers, and Mileposts, the “Departmental accountability” report published by the Washington State DOT (WSDOT) each quarter to inform the legislature and public about how the Department is responding to public direction and spending taxpayer resources.<sup>6</sup> Agencies now use performance measures as part of everyday practice to help make informed decisions.

WSDOT uses performance measures to help allocate resources, determine the effectiveness of a variety of programs, and help plan and prioritize system improvements, primarily from an operations perspective. A variety of measures are computed. Not all of these measures are routinely reported outside of the Department, but key statistics that describe either the current state-of-the-system, trends that are occurring, or the effectiveness of major policies are reported quarterly as part of the Department’s efforts to clarify why it is taking specific actions and to improve its accountability to the public and public decision makers. The planning groups use performance measures to compare the relative performance of various corridors or roadway sections under study. These aggregated statistics can also be converted to unit values (e.g., person hours of delay per mile) to further improve the ability to compare and prioritize the relative condition of corridors or roadway segments.

The operations agencies track these outcome performance measures:

#### Sample of Operations Planning/Output Measures

- number of loop detectors deployed
- number of loops functioning currently
- percentage of loops functioning during a year
- number of service patrol vehicles currently deployed
- number of hours of service patrol efforts supplied by WSDOT
- number of motorist assists by type of assistance provided
- number, duration, and severity of incidents by location (roadway segment) and type of incident

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<sup>6</sup> See <http://www.wsdot.wa.gov/accountability/> for more information on WSDOT’s program.

### Operations Planning/Outcome Measures

- average vehicle volume by location and time of day and by type of facility (HOV/GP lane)
- average person volume by location and time of day and by type of facility
- frequency of severe congestion (LOS F) by location
- average travel time by corridor and major trip (O/D pairs)
- 95th percentile travel time by corridor and major trip (also reported as Buffer Time)
- number of very slow trips (half of free-flow speed) that occur each year by time of day and major trip
- amount of lost efficiency (speeds less than 45 mph) by location
- number of times that HOV lanes fail to meet adopted travel time performance standards
- percentage of HOV lane violators observed by monitoring location

### 3. DATA, ANALYSIS METHODS, AND PERFORMANCE MEASURES

This chapter provides documentation on the archived traffic detector data as well as the analysis methods used to process and summarize the data. The definition and calculation procedures for the performance measures reported in the Mobility Monitoring Program are also included. The chapter is organized as follows:

- *Participating cities and their archived data* – presents information on the cities that participated by submitting archived data, including the type of sensor technology used to collect the data, the level of detail of the archived data, and the data elements that were submitted.
- *Overview of data processing* – provides an overview of the data processing steps used to prepare the data for analysis, including pre-processing, data quality checking, and aggregation to a common data standard, and finally the mobility and reliability analysis.
- *Data quality procedures* – describes the data quality checks used in preparing the archived data for analysis.
- *Congestion and reliability measures* – provides definitions and calculation procedures for the performance measures reported in this report.

#### Participating Cities and Their Archived Data

Public and private agencies from a total of 29 cities participated in the Mobility Monitoring Program by providing archived traffic detector data from 2003 (Table 2). The format and organization of the archived data varies considerably among cities. To provide more consistency and reduce ambiguity, the project team developed some basic guidelines on preferred data formats (Figure 1). These preferred data formats were developed to clarify exactly what data was needed, as well as to “standardize” the archived data (with some minor variation) being submitted to the Program. Some of the preferred data formats and organization arose from how the data were to be processed in the SAS application software. Other details of organization were included because they were already present and consistent in the majority of cities submitting archived data. Note that the preferred data formats reference data elements contained in national ITS standards like the Traffic Management Data Dictionary.<sup>7</sup>

In future years, the project team will encourage use of these preferred data formats to reduce our pre-processing burden and standardize our initial data processing software for all cities. Because participation and data submission is strictly voluntary, however, we are in a position to accept the data format and organization that is most convenient for cities to provide.

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<sup>7</sup> See <http://www.ite.org/tmdd/index.asp> for more details.

**Table 2. Participating Cities and Agencies for 2003 Archived Data**

<b>City #</b>	<b>Participating City</b>	<b>Contact Agency/Group</b>	<b>Historical Data Since</b>
1	Albany, NY	New York State DOT	2001
2	Atlanta, GA	Georgia DOT	2000
3	Austin, TX	Texas DOT	2000
4	Baltimore, MD	Maryland SHA & Univ. of Maryland	2003
5	Charlotte, NC	North Carolina DOT	2001
6	Cincinnati, OH-KY	ARTIMIS & Kentucky Transportation Cabinet	2000
7	Dallas, TX	Texas DOT & TTI	2003
8	Detroit, MI	Michigan DOT	2000
9	El Paso, TX	Texas DOT	2003
10	Hampton Roads, VA	Virginia DOT & ADMS Virginia	2000
11	Houston, TX	Texas DOT & TTI	2000
12	Los Angeles, CA	Caltrans & PeMS	2000
13	Louisville, KY	Kentucky Transportation Cabinet	2001
14	Milwaukee, WI	Wisconsin DOT	2001
15	Minneapolis-St. Paul, MN	Minnesota DOT & Univ. of Minnesota-Duluth	2000
16	Orange County, CA	Caltrans & PeMS	2003
17	Orlando, FL	Florida DOT	2001
18	Philadelphia, PA	Mobility Technologies	2001
19	Phoenix, AZ	Arizona DOT	2000
20	Pittsburgh, PA	Mobility Technologies	2001
21	Portland, OR	Oregon DOT	2001
22	Riverside-San Bernardino, CA	Caltrans & PeMS	2003
23	Sacramento, CA	Caltrans & PeMS	2002
24	Salt Lake City, UT	Utah DOT	2002
25	San Antonio, TX	Texas DOT	2000
26	San Diego, CA	Caltrans & PeMS	2001
27	San Francisco, CA	Caltrans & PeMS	2003
28	Seattle, WA	Washington State DOT	2000
29	Washington, DC	Maryland SHA & Univ. of Maryland, Virginia DOT & ADMS Virginia	2002

## **Figure 1. Preferred Archived Data Formats for Mobility Monitoring Program (Page 1 of 2)**

### **PREFERRED DATA FORMATS FOR FHWA'S MOBILITY MONITORING PROGRAM**

The document summarizes the preferred formats for submitting data to FHWA's Mobility Monitoring Program. While other formats are acceptable, the following formats are encouraged for unambiguous and efficient data exchange. The required data submissions should include two distinct datasets: 1) actual traffic data records; and 2) traffic sensor location information. Many of the data elements have already been defined by national ITS standards (e.g., Traffic Management Data Dictionary, TMDD) and are indicated as such.

#### **File Formats And Organization**

- The traffic data records should be submitted in delimited ASCII-text files. Acceptable delimiting characters include commas, tabs, or spaces.
- Missing or null values should be indicated by providing a blank space or other null value code in the respective field. Metadata should document particular error codes (e.g., "-1" or "255") and meaning if these error codes are contained in the dataset.  
A separate delimited text file should be submitted for each day for each city, with data from all sensor locations being included in this single daily file. The file should be named to include a location or agency code and a date stamp (YYYYMMDD format). For example, "phx\_20040101.txt" contains data for Jan. 1, 2004 for Phoenix, Arizona.
- The text files should be compressed for transmission using industry standard PC (\*.zip) or UNIX (\*.z or \*.gz) compression software.
- The archived traffic data should be submitted by CD-ROM or FTP.

#### **Data Elements**

- The data should be aggregated to 5-minute time periods for each travel lane. Even 5-minute time periods should be used (e.g., 12:00 am, 12:05 am, 12:10 am, etc.).
- Each row of the delimited text file should contain the following data elements:
  1. Time (HH:MM with 24-hour clock) and date (MM/DD/YYYY) stamp. Documentation should indicate whether this is a start or ending time;
  2. Detector identifier (DETECTOR\_Identifier\_identifier in TMDD);
  3. Vehicle traffic volume count (DETECTOR\_VehicleCount\_quantity);
  4. Average lane occupancy, if available (DETECTOR\_Occupancy\_percent); and
  5. Average speed or travel time (LINK\_SpeedAverage\_rate or LINK\_TravelTime\_quantity).
- If the data have been aggregated from a shorter time period (e.g., 20 seconds or 1 minute), each 5-minute record should indicate how many detailed records were used in the summary statistic calculation. This "completeness" value is reported as the percentage of the total possible records that are included in the summary statistic.

## **Figure 1. Preferred Archived Data Formats for Mobility Monitoring Program (Page 2 of 2)**

### **Sensor Location Information**

- Location information should be provided for each unique traffic sensor. The location information can be provided in delimited text files, spreadsheets, or databases.
- The location information should include the following for each traffic sensor that reports data at any time during the year:
  1. Detector identifier (same as used in the traffic data records, DETECTOR\_Identifier\_identifier);
  2. Lane designation or code (DETECTOR\_LaneNumber\_code);
  3. Number of directional through travel lanes at that location (LINK\_LaneCount\_quantity);
  4. Roadway name and/or designation (LINK\_RoadDesignator\_number);
  5. Roadway direction (DETECTOR\_Direction\_code);
  6. Roadway facility type, such as mainlane, HOV, entrance ramp, etc. (LINK\_Type\_code);
  7. A linear distance reference such as roadway milepost (in miles or kilometers);
  8. Sensor activation date which indicates when the sensor began providing valid data; and
  9. Sensor de-activation date which indicates when the sensor stopped providing valid data. If the sensor is still active, this field could be blank or null values.

### **Additional Documentation**

Additional documentation on the archived data is encouraged and appreciated. This documentation could include information on the following aspects:

- Data collection technology and source;
- Data quality control checks and summary results;
- Data transformation or estimation processes (e.g., equations used to estimate speeds from single loops); and
- Other information that would help analysts better interpret the quality and content of the ITS data archives.

The mobility and reliability measure calculations in the Mobility Monitoring Program are built around estimated travel times for directional freeway routes. However, as Table 3 indicates, nearly all of the participating cities have traffic management centers that collect traffic speeds and volumes at specific points along the freeway route. For 28 of the 29 total cities (all except Houston), the data were collected at point locations using a variety of traffic sensor technologies including single and double inductance loops, microwave radar, passive acoustic, and video image processing. For Houston, link travel times are collected by a toll tag-based system, and these link travel times are supplemented with volume trend data from a limited number of double inductance loops. In many cities, multiple sensor technologies were used to collect the traffic speed and volume data. All of these technologies use a small, fixed zone of detection, and the traffic speed and volume measurements are taken as vehicles pass through this zone. The last section in this chapter describes how these point speeds and volumes are transformed to travel time estimates for directional freeway routes.

Table 3 also indicates the level of detail at which the archived data is submitted to the Mobility Monitoring Program. The time aggregation level varies widely, from 20 seconds in San Antonio to 15 minutes in several areas. In some cases, the data are collected in smaller time intervals (e.g., 20 seconds to 2 minutes) but aggregated to larger time intervals for archiving purposes. Most of the archived data are provided on a per lane basis.

The extent of freeway monitoring coverage is shown in Table 4, which reports the percentage of each city's freeway system for which archived data are available. The freeway coverage ranges from 6 percent in Dallas to 100+ percent in Milwaukee and Salt Lake City (both cities monitor freeway miles outside of the urban area). The average coverage of freeway centerline miles is 46 percent, whereas the average coverage of freeway lane-miles is slightly higher at 53 percent. Generally speaking, only half of the urban freeway mileage in the 29 participating cities is covered in this report's analysis. For all 29 cities, there are nearly 3,000 total freeway miles on which real-time traffic data is being collected and archived.

Readers should note that the participating cities were not chosen based on their monitoring coverage, but on their ability to provide archived data. In many cities, this freeway coverage includes the most congested freeways as well as some lightly congested freeway routes. In several cities, the monitoring coverage does not include very congested routes for a variety of reasons (e.g., reconstruction, upcoming deployment, etc.).

**Table 3. Summary of Data Collection Technologies and Data Level of Detail in 2003**

Participating City	Traffic Sensor Technology	Data Level of Detail	
		Time	Space
Albany, NY	loop detectors	15 minutes	by lane
Atlanta, GA	video imaging, microwave radar	15 minutes	by lane
Austin, TX	loop detectors	1 minute	by lane
Baltimore, MD	microwave radar, loop detectors	5 minutes	by lane
Charlotte, NC	microwave radar	30 seconds	by lane
Cincinnati, OH-KY	loop detectors, microwave radar, video imaging	15 minutes	by direction
Dallas, TX	video imaging, loop detectors, microwave radar	5 minutes	by lane
Detroit, MI	loop detectors	1 minute	by lane
El Paso, TX	loop detectors, microwave radar	1 minute	by direction
Hampton Roads, VA	loop detectors, microwave radar	5 minutes	by direction
Houston, TX	probe vehicle (toll tags); also loop detectors, video imaging, and microwave radar		vehicle-based link travel times
Los Angeles, CA	loop detectors	5 minutes	by direction
Louisville, KY	microwave radar, video imaging	15 minutes	by direction
Milwaukee, WI	loop detectors, microwave radar, video imaging	5 minutes	by lane
Minneapolis-St. Paul, MN	loop detectors	30 seconds	by lane
Orange County, CA	loop detectors	5 minutes	by direction
Orlando, FL	loop detectors	1 minute	by lane
Philadelphia, PA	microwave radar, passive acoustic detectors	5 minutes	by lane
Phoenix, AZ	loop detectors, passive acoustic detectors	5 minutes	by lane
Pittsburgh, PA	microwave radar, passive acoustic sensors	5 minutes	by lane
Portland, OR	loop detectors	15 minutes	by lane
Riverside-San Bernardino, CA	loop detectors, microwave radar	5 minutes	by direction
Sacramento, CA	loop detectors, microwave radar	5 minutes	by direction
Salt Lake City, UT	loop detectors, acoustic detectors, microloops	15 minutes	by lane
San Antonio, TX	loop detectors, acoustic detectors	20 seconds	by lane
San Diego, CA	loop detectors	5 minutes	by direction
San Francisco, CA	loop detectors, microwave radar	5 minutes	by direction
Seattle, WA	loop detectors	5 minutes	by lane
Washington, DC			
- Maryland	microwave radar, loop detectors (MD)	5 minutes	by lane
- Virginia	loop detectors (VA)	1 minute	by lane

**Source:** Conversations with agency representatives and the 2002 ITS Deployment Tracking Survey (<http://itsdeployment2.ed.ornl.gov/its2002/default.asp>)

**Table 4. Summary of 2003 Freeway Archived Data Coverage**

Participating City	Centerline miles			Lane-miles		
	Instru- mented	Total	Coverage (%)	Instru- mented	Total	Coverage (%)
Albany, NY	17	104	16%	159	550	29%
Atlanta, GA	91	302	30%	862	2,300	37%
Austin, TX	23	107	21%	146	590	25%
Baltimore, MD	28	290	10%	167	1,543	11%
Charlotte, NC	15	93	16%	89	488	18%
Cincinnati, OH-KY	54	184	29%	367	1,035	35%
Dallas, TX	19	302	6%	151	1,904	8%
Detroit, MI	110	282	39%	751	1,810	41%
El Paso, TX	31	52	60%	193	288	67%
Hampton Roads, VA	20	191	10%	158	970	16%
Houston, TX	236	383	62%	1,764	2,548	69%
Los Angeles, CA	411	463	89%	3,697	4,253	87%
Louisville, KY	26	137	19%	147	670	22%
Milwaukee, WI	118	111	106%	698	605	115%
Minneapolis-St. Paul, MN	219	317	69%	1,194	1,595	75%
Orange County, CA	178	195	91%	1,557	1,530	102%
Orlando, FL	32	166	19%	230	775	30%
Philadelphia, PA	126	352	36%	687	2,095	33%
Phoenix, AZ	83	214	39%	729	1,360	54%
Pittsburgh, PA	101	292	35%	541	1,228	44%
Portland, OR	54	139	39%	245	725	34%
Riverside-San Bernardino, CA	57	143	40%	469	918	51%
Sacramento, CA	52	109	48%	370	715	52%
Salt Lake City, UT	95	84	113%	656	545	120%
San Antonio, TX	90	212	42%	576	1,073	54%
San Diego, CA	134	254	53%	1,065	1,848	58%
San Francisco, CA	322	342	94%	2,349	2,455	96%
Seattle, WA	120	249	48%	889	1,763	50%
Washington, DC	73	309	24%	468	1,975	24%
<b>Total</b>	2,935	6,382	46%	21,374	40,149	53%

**Source:** The estimates for total freeway centerline miles and total freeway lane-miles are from FHWA's Highway Performance Monitoring System and TTI's Urban Mobility Study (<http://mobility.tamu.edu/ums>).

Real-time traffic data collection and archiving processes have been developed independently in most of the cities and the details of these processes vary among the cities. As a general rule, traffic centers at least have the capability to archive data from their traffic detector systems. In a few cases, this capability is not used because of priorities elsewhere in the traffic center, but it is clear that traffic center software is being constructed with archiving as a function. However, the state of the practice in traffic center archiving is still fairly primitive. The most common practice is to transfer the data to a storage device where they reside in simple text file formats without an active information management system. Quality control is seldom performed at this level and access to the data is provided on a case-by-case basis without the benefit of a query or reporting structure – data are simply provided in whatever file formats are used to store them.

The typical steps from field data collection to data archiving are as follows:

1. Traffic data are collected by detectors and accumulated in roadside controllers. These field measurements are typically collected for each individual lane of traffic. At 20-second to 2-minute intervals, the roadside controllers transmit the data to a central location, typically a traffic center.
2. Some cities perform quality control on field-collected data, but this checking is simple and based on minimum and maximum range value thresholds.
3. Cities that use single inductance loop detectors can measure only volumes and lane occupancies directly. In these cases, speed estimation algorithms are used to compute spot speeds from volumes and lane occupancies. These speed estimation algorithms vary among cities.
4. Internal processes at the traffic center aggregate the traffic data to specified time intervals for archival purposes. These time intervals vary from 20 seconds (no aggregation) to 15 minutes. In some cases, the data are also aggregated across all lanes in a given direction at a sensor location.
5. The aggregated data are then stored in text files or databases unique to each traffic center. CDs or DVDs are routinely created at the traffic centers to offload some of the storage burden and to satisfy outside requests for the data.

Calibration and maintenance of field equipment and communications are nearly universal problems. The main impediment is lack of resources to devote to these tasks; traffic center budgets are limited and must be used to address a multitude of issues. Calibration—at least to very tight tolerances—is not seen as a priority, given that operators focus on a broad range of operating conditions rather than precise volume and speed measurements. Or in some cases traffic managers may be willing to accept a certain level of data quality to satisfy only their current operations applications. This philosophy may be changing as a result of more stringent data requirements for traveler information purposes (e.g., travel time messages on variable message signs). However, we have found the current data quality requirements used by traffic centers to be quite coarse for supporting their traditional operations activities, such as incident detection and ramp meter control.

Maintenance is a problem (due primarily to funding limitations) even when detectors are known to be producing erroneous or no data. The problem is exacerbated where loop or other pavement-based detectors are used because most agencies are reluctant to shut down traffic on heavily traveled freeways just for detector repair. This is not to say that faulty detectors are never repaired, but maintenance is often postponed to coincide with other roadway activities, which helps spread the cost burden as well.

Field checking of detectors is done periodically but no standardized procedures are used across all cities. If a detector is producing values that are clearly out of range, inspection and maintenance are usually performed. However, calibration to a known standard is rarely, if ever, performed. This means that more subtle errors may go undetected. As most traffic centers typically do not require highly accurate data for most of their operations, this approach is reasonable and practical. Work zones exacerbate these problems and often contractors unknowingly sever communication lines or pave over inductance loops.

### **Overview of Data Processing**

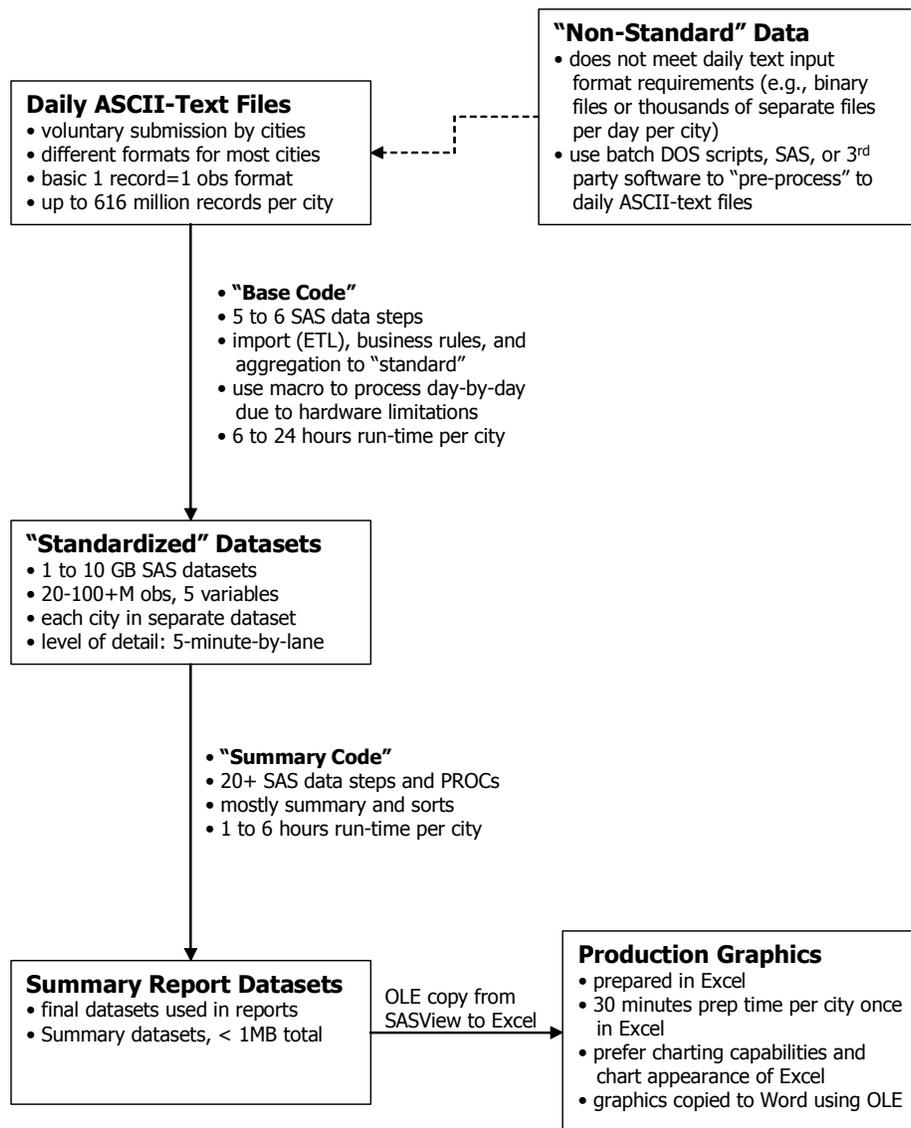
This section presents a brief overview of the data processing steps used to transform the archived data into congestion and reliability statistics. The relatively mundane topic of data processing is included here because of its departure from traditional traffic data monitoring practices. In analyzing the archived traffic data from the 29 participating cities, the project team processed about 6 billion data records, with a total computer processing time best measured in days or weeks.

Figure 2 shows an overview of the data processing steps used to prepare and analyze the archived data. Perhaps the greatest challenge in the data processing was “standardizing” the archived datasets from 29 different cities, or numerous different legacy systems. In many cases, the lack of adequate metadata (i.e., descriptive information about the archived data) complicates the process of properly interpreting and analyzing the archived data. For example, each city’s dataset may use different data error codes to indicate various hardware or software failures. Or similar data error codes could be used by several cities to mean different types of data errors. In other cases, various flaws, nuances, or characteristics in the archived data may be known by the data collector but undocumented, and potentially go undetected by the project team unless careful study was initiated. The experience of the project team indicates that dealing with legacy system data is much more manageable when metadata is used to describe the origin, lineage, characteristics, and subtle nuances of the archived data.

The data processing for the Mobility Monitoring Program is primarily accomplished using SAS software on a Microsoft Windows platform for two reasons: 1) the project team’s previous software programming experience with SAS; and 2) ability and flexibility of SAS to handle a wide range of complex computations on very large datasets. Many other relational database management systems (RDBMS) could also be used to accomplish the same data processing tasks as was performed in SAS.

The data processing flows shown in Figure 2 have been optimized for the use of SAS in generating annual mobility and reliability reports. Some of the data processing steps, however, may be similar for other data archiving and analysis activities. For example, the first step that includes the base code is known as extraction, transformation and loading (ETL) in the data warehouse industry and is a common function for most data warehouse projects. The project team has attempted to standardize the software code as much as possible for ease and automation of data processing. However, the software code is custom-tailored (mostly in the base code) to meet the different formats and organization of submitted archived data.

**Figure 2. Overview of Data Processing within Mobility Monitoring Program**



The data processing as shown in Figure 2 would ideally start with daily ASCII-text files that meet the preferred data formats indicated in Figure 1. However, many cities submit data in a form that requires pre-processing (e.g., binary file formats or thousands of separate files per city per day). Pre-processing this non-standard data requires extra steps and time at the beginning to prepare the archived data to be processed using the base code.

Once the submitted archived data meets basic formatting and organization requirements, it is processed using the base code. This software code: 1) imports the data to SAS; 2) performs data quality checking; 3) aggregates detailed data to a common standard (currently 5-minute lane-by-lane); and 4) generates summary statistics on the data quality checking and processing steps. Some of these steps, such as the data quality checks, have been standardized for all cities. Other steps are unique to each city based on the aggregation level and other data characteristics. This step involves the longest amount of processing time, sometimes taking up to 24 hours for the largest cities with the most detailed data (e.g., 20-seconds, lane-by-lane).

The standardized datasets are produced as a result of the base code. The data elements and table structure of these datasets are very similar with a few exceptions (e.g., some cities are 5-minute by-lane, others may be 15-minute by direction). Thus the summary code, which contains the mobility and reliability measure calculations described later in this chapter, has largely been standardized for all cities. The standardized datasets are analogous to the database tables that would be kept on-line in an RDBMS environment.

The summary code performs all mobility and reliability measure calculations, and produces relatively small datasets (less than 1 megabyte total) that are then used to produce the charts and tables shown throughout this report and the city report appendices. Microsoft Excel was selected for the ease of producing report-ready graphics.

In summary, the data processing steps and software code used to analyze the archived data has developed in this way as a result of: 1) previous project team experience; and 2) the specific application of creating annual mobility and reliability reports. Different approaches are very likely given different implementation scenarios and development teams. Several of the data processing steps conducted in the Mobility Monitoring Program may be relevant to other data archiving or data warehouse activities. In particular, the base code contains data quality checking procedures and other steps that are most likely required in other data warehouse efforts. The summary code contains congestion and reliability measure calculations that are described in later in this chapter and may be useful to others developing performance measure programs.

### **Data Quality Checking**

The topic of data quality is included here because of its overall importance in checking and evaluating the validity of archived data. Readers should note that the project team has not been able to systematically assess data accuracy. This means that the traffic speeds and volumes in the archived data could be systematically higher or lower (e.g.,  $\pm 10$  to 20 percent) than true speeds and still be within the range of possible data values that pass quality control.

Table 5 presents the data quality checks that were used in processing the 2003 archived data. The data quality checks have been developed from these sources:

- Current practices in other traffic centers or data archiving systems;
- Suggested practices recommended in the literature; and
- Practices found to be necessary from project team analysis of the archived data.

These data quality checks can be characterized as basic validity checks and should detect major problems with data errors. More subtle erroneous or suspect data could potentially go undetected with these basic rules. The project team is reviewing the use of more sophisticated data quality checking, and we will continue to balance the sophistication of the data quality checking with the amount of available data processing time. The data quality checks shown in Table 5 may evolve as the project team accumulates more experience with the archived data. More sophisticated quality checks could include tests like these:

- Rapid fluctuations in values across successive time periods;
- Detectors in adjacent lanes at the same location reporting significantly different values or trends;
- Detectors in adjacent upstream or downstream locations reporting significantly different values or trends;
- Detectors from multiple locations reporting the same values (indicative of a system problem);
- Reported values that are significantly different from the location's history for similar days of the calendar.

The results of these quality control checks are shown in Table 6, which reports the percent of the submitted data that passed the quality control checks. The table presents traffic volume and speed data quality separately, as some of the validity checks could have rejected one of the data values but not the other. Also note that Table 6 only evaluates the validity of the data that was archived and submitted. This table does not reflect data that are missing and were never reported because of various hardware or software failures.

Table 7 summarizes information on data completeness or availability, another dimension of data quality. The data completeness measures the number of available data values to the number of total possible values that one could expect (given the number of sensors and a polling rate). For example, if the data are reported by 5-minute time interval, 288 data values or records per day per detector are to be expected (i.e., 1,440 minutes per day divided by 5-minute periods equals 288 records). Table 7 reports data completeness for the original dataset as submitted by participating cities, as well as the analysis dataset (after quality control and imputation) that is used for mobility and reliability performance measure calculations.

Interested readers should refer to the September 2004 FHWA report on traffic data quality measurement for more details on calculating the validity and completeness measures, as well as several other data quality measures.<sup>8</sup>

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<sup>8</sup> Battelle, Cambridge Systematics, and Texas Transportation Institute. *Traffic Data Quality Measurement: Final Report*. Federal Highway Administration, September 2004.

**Table 5. 2003 Data Validity Checks in the Mobility Monitoring Program**

Quality Control Test and Description	Sample Code with Threshold Values	Action
<u>Controller error codes</u> <ul style="list-style-type: none"> <li>Special numeric codes that indicate that controller or system software has detected an error or a function has been disabled.</li> </ul>	If VOLUME={code} or OCC={code} or SPEED={code} where {code} typically equals “-1” or “255”	<ul style="list-style-type: none"> <li>Set values with error codes to missing/null, assign missing value flag/code.</li> </ul>
<u>No vehicles present</u> <ul style="list-style-type: none"> <li>Speed values of zero when no vehicles present</li> <li>Indicates that no vehicles passed the detection zone during the detection time period.</li> </ul>	If SPEED=0 and VOLUME=0 (and OCC=0)	<ul style="list-style-type: none"> <li>Set SPEED to missing/null, assign missing value code</li> <li>No vehicles passed the detection zone during the time period.</li> </ul>
<u>Consistency of elapsed time between records</u> <ul style="list-style-type: none"> <li>Polling period length may drift or controllers may accumulate data if polling cycle is missed.</li> <li>Data collection server may not have stable or fixed communication time with field controllers.</li> </ul>	Elapsed time between consecutive records exceeds a predefined limit or is not consistent	<ul style="list-style-type: none"> <li>Action varies. If polling period length is inconsistent, volume-based QC rules should use a volume flow rate, not absolute counts.</li> </ul>
<u>Duplicate records</u> <ul style="list-style-type: none"> <li>Caused by errors in data archiving logic or software process.</li> </ul>	Detector and date/time stamp combination are identical.	<ul style="list-style-type: none"> <li>Remove/delete duplicate records.</li> </ul>
<u>QC1-QC3: Logical consistency tests</u> <ul style="list-style-type: none"> <li>Typically used for date, time and location.</li> <li>Caused by various types of failures.</li> </ul>	If DATE={valid date value} (QC1) If TIME={valid time value} (QC2) If DET_ID={valid detector location value} (QC3)	<ul style="list-style-type: none"> <li>Write to off-line database and/or remove records with invalid date, time or location values.</li> </ul>
<u>QC4: Maximum volume</u> <ul style="list-style-type: none"> <li>Traffic flow theory suggests a maximum traffic capacity.</li> </ul>	If VOLUME > 17 (20 sec.) If VOLUME > 25 (30 sec.) If VOLUME > 250 (5 min.) If VPHPL > 3000 (any time period length)	<ul style="list-style-type: none"> <li>Assign QC flag to VOLUME, write failed record to off-line database, set VOLUME to missing/null.</li> </ul>
<u>QC5: Maximum occupancy</u> <ul style="list-style-type: none"> <li>Empirical evidence suggests that all data values at high occupancy levels are suspect.</li> <li>Caused by detectors that may be “stuck on.”</li> </ul>	If OCC > 95% (20 to 30 sec.) If OCC > 80% (1 to 5 min.)	<ul style="list-style-type: none"> <li>Assign QC flag to VOLUME, OCCUPANCY and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY and SPEED to missing/null</li> </ul>
<u>QC6: Minimum speed</u> <ul style="list-style-type: none"> <li>Empirical evidence suggests that actual speed values at low speed levels are inaccurate.</li> </ul>	If SPEED < 5 mph	<ul style="list-style-type: none"> <li>Assign QC flag to SPEED, write failed record to off-line database, set SPEED value to missing/null</li> </ul>
<u>QC7: Maximum speed</u> <ul style="list-style-type: none"> <li>Empirical evidence suggests that actual speed values at high speed levels are suspect.</li> </ul>	If SPEED > 100 mph (20 to 30 sec.) If SPEED > 80 mph (1 to 5 min.)	<ul style="list-style-type: none"> <li>Assign QC flag to SPEED, write failed record to off-line database, set SPEED value to missing/null</li> </ul>

**Table 5. 2003 Data Validity Checks in the Mobility Monitoring Program (Continued)**

Quality Control Test and Description	Sample Code with Threshold Values	Action
<u>Maximum reduction in speed</u> <ul style="list-style-type: none"> <li>Empirical evidence suggests that speed reductions greater than some maximum value are suspect.</li> <li>Used only for AVI probe vehicle data that reports space mean speeds.</li> </ul>	If $SPEED_{n+1} < (0.45 \times SPEED_n)$	<ul style="list-style-type: none"> <li>Assign QC flag to SPEED, write failed record to off-line database, set SPEED value to missing/null</li> </ul>
<u>QC8: Multi-variate consistency</u> <ul style="list-style-type: none"> <li>Zero speed values when volume (and occupancy) are non-zero</li> <li>Speed trap not functioning properly</li> </ul>	If $SPEED = 0$ and $VOLUME > 0$ (and $OCC > 0$ )	<ul style="list-style-type: none"> <li>Assign QC flag to SPEED, write failed record to off-line database, set SPEED value to missing/null</li> </ul>
<u>QC9: Multi-variate consistency</u> <ul style="list-style-type: none"> <li>Zero volume values when speed is non-zero.</li> <li>Unknown cause.</li> </ul>	If $VOLUME = 0$ and $SPEED > 0$	<ul style="list-style-type: none"> <li>Assign QC flag to VOLUME, write failed record to off-line database, set VOLUME to missing/null</li> </ul>
<u>QC10: Multi-variate consistency</u> <ul style="list-style-type: none"> <li>Zero speed and volume values when occupancy is non-zero.</li> <li>Unknown cause.</li> </ul>	If $SPEED = 0$ and $VOLUME = 0$ and $OCC > 0$	<ul style="list-style-type: none"> <li>Assign QC flag to VOLUME, OCCUPANCY and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY and SPEED to missing/null</li> </ul>
<u>QC11: Truncated occupancy values of zero</u> <ul style="list-style-type: none"> <li>Caused when software truncates or rounds to integer value</li> <li>Calculate maximum possible volume (MAXVOL) for an occupancy value of "1":</li> </ul>	If $OCC = 0$ and $VOLUME > MAXVOL$ where $MAXVOL = (2.932 * ELAPTIME * SPEED) / 600$	<ul style="list-style-type: none"> <li>Assign QC flag to VOLUME, OCCUPANCY and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY and SPEED to missing/null</li> </ul>
<u>QC12: Maximum estimated density</u> <ul style="list-style-type: none"> <li>Caused by improbable combinations of volume and speed.</li> <li>Traffic flow theory suggests that vehicle density rarely exceeds 220 vehicles per lane per mile.</li> </ul>	IF $((VOLUME * (3600 / NOM\_POLL)) / SPEED) > 220$ where NOM_POLL is the nominal polling cycle length in seconds.	<ul style="list-style-type: none"> <li>Assign QC flag to VOLUME, OCCUPANCY and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY and SPEED to missing/null</li> </ul>
<u>QC13: Consecutive identical volume-occupancy-speed values</u> <ul style="list-style-type: none"> <li>Research and statistical probability indicates that consecutive runs of identical data values are suspect.</li> <li>Typically caused by hardware failures.</li> </ul>	No more than 8 consecutive identical volume-occupancy-speed values. That is, the volume AND occupancy AND speed values have more than 8 consecutive identical values, respectively. Zero ("0") values are included in this check.	<ul style="list-style-type: none"> <li>Assign QC flag to VOLUME, OCCUPANCY and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY and SPEED to missing/null</li> </ul>

**Table 6. Summary of 2003 Freeway Archived Data Validity**

Participating City	Validity (%)	
	Volume data	Speed data
Albany, NY	55%	54%
Atlanta, GA	94%	89%
Austin, TX	80%	56%
Baltimore, MD	99%	73%
Charlotte, NC	92%	93%
Cincinnati, OH-KY	76%	74%
Dallas, TX	100%	96%
Detroit, MI	100%	99%
El Paso, TX	55%	49%
Hampton Roads, VA	75%	58%
Houston, TX	n.a.	98%
Los Angeles, CA	98%	99%
Louisville, KY	93%	93%
Milwaukee, WI	80%	82%
Minneapolis-St. Paul, MN	83%	78%
Orange County, CA	98%	99%
Orlando, FL	n.a.	n.a.
Philadelphia, PA	100%	99%
Phoenix, AZ	72%	68%
Pittsburgh, PA	100%	99%
Portland, OR	62%	85%
Riverside-San Bernardino, CA	96%	100%
Sacramento, CA	100%	100%
Salt Lake City, UT	62%	53%
San Antonio, TX	96%	84%
San Diego, CA	100%	99%
San Francisco, CA	100%	100%
Seattle, WA	85%	100%
Washington, DC	100%	98%

**Notes:** Validity is reported as the percentage of submitted data values that passed the quality control rules specified in Table 5. See *Traffic Data Quality Measurement: Final Report* (footnote 8 on page 24) for more details on data quality measure calculation.

**Table 7. Summary of 2003 Freeway Archived Data Completeness**

Participating City	Completeness (%) Original Data		Completeness (%) Analysis Data	
	Volume data	Speed data	Volume data	Speed data
Albany, NY	69%	69%	38%	37%
Atlanta, GA	17%	17%	57%	54%
Austin, TX	97%	97%	77%	59%
Baltimore, MD	77%	77%	63%	57%
Charlotte, NC	60%	61%	55%	57%
Cincinnati, OH-KY	47%	47%	44%	41%
Dallas, TX	76%	76%	46%	44%
Detroit, MI	61%	61%	61%	62%
El Paso, TX	98%	98%	33%	33%
Hampton Roads, VA	75%	75%	49%	39%
Houston, TX	n.a.	n.a.	n.a.	56%
Los Angeles, CA	100%	99%	98%	98%
Louisville, KY	82%	82%	82%	76%
Milwaukee, WI	100%	100%	80%	77%
Minneapolis-St. Paul, MN	100%	100%	83%	79%
Orange County, CA	99%	94%	97%	93%
Orlando, FL	n.a.	n.a.	n.a.	n.a.
Philadelphia, PA	92%	92%	92%	91%
Phoenix, AZ	89%	89%	63%	60%
Pittsburgh, PA	94%	94%	94%	93%
Portland, OR	98%	98%	84%	83%
Riverside-San Bernardino, CA	71%	67%	70%	67%
Sacramento, CA	88%	84%	88%	83%
Salt Lake City, UT	95%	95%	44%	38%
San Antonio, TX	63%	63%	67%	66%
San Diego, CA	95%	93%	95%	92%
San Francisco, CA	98%	92%	97%	92%
Seattle, WA	79%	79%	80%	81%
Washington, DC	52%	52%	33%	33%

**Note:** Completeness is reported as the percentage of data values available for use. It is calculated as the ratio of total available data values to total expected data values. See *Traffic Data Quality Measurement: Final Report* (footnote 8 on page 24) for more details on data quality measure calculation.

## Congestion and Reliability Measure Calculations

With the exception of Houston, which reported travel times collected with their AVI system, archived data from the participating cities consisted of traffic speeds and volumes collected at various points along the freeway routes. Because the mobility and reliability performance measures are based on travel time, the project team estimated freeway route travel times from the spot speeds. Figure 3 illustrates the process whereby lane-by-lane volumes and speeds are used as the basis for estimating freeway route travel times and vehicle-miles of travel (VMT). The steps are as follows:

1. If data are reported by lane, the lane-by-lane data are combined into a “station” (e.g., all lanes in a direction). Traffic volumes are summed across all lanes, and traffic speeds are a weighted average, with weighting based on respective traffic volumes.
2. Link properties were estimated from “station” data by assuming that each detector had a zone of influence equal to half the distance to the detectors immediately upstream and downstream from it. The measured speeds were then assumed to be constant within each zone of influence, and travel times were calculated using the equivalent link lengths. VMT were also computed in this way using traffic volume.
3. Freeway links were then grouped with other similar adjacent link into analysis sections, which were typically 5 to 10 miles in length. The beginning and end points of analysis sections were typically selected to coincide with major highway interchanges or other locations where traffic conditions were expected to change because of traffic or roadway characteristics.

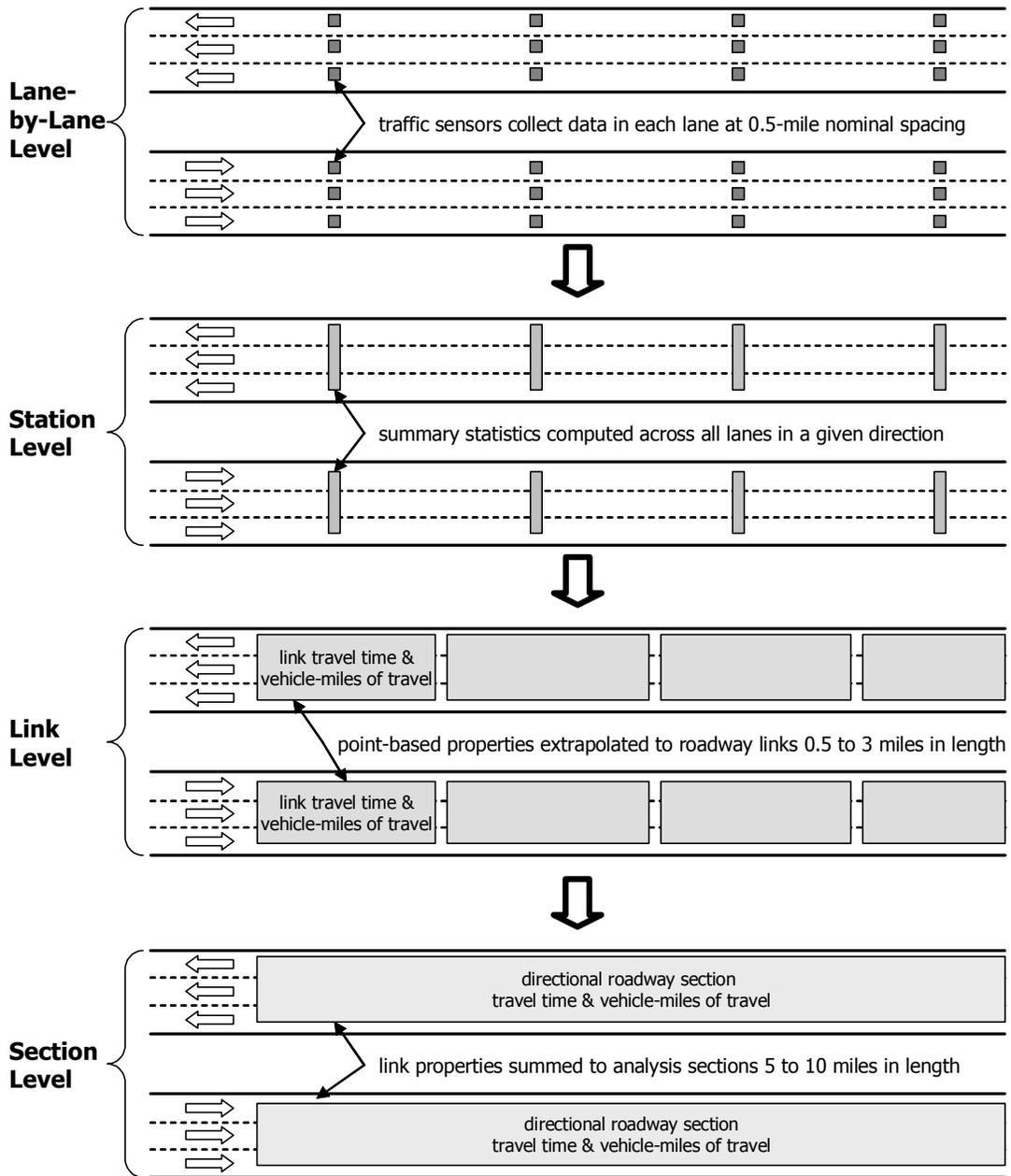
Travel times for these analysis sections then served as the basis for all subsequent mobility and reliability measure calculations. The specifics of these performance measure calculations are contained later in this section. Readers should note that equations using travel time refer to the analysis section travel times as described above.

Several other aspects and definitions used in preparing the archived data for analysis were:

- Holidays were excluded from the weekday peak period analysis, as holidays were considered to be atypical of normal travel patterns. Holidays are included in several daily total statistics, which also include weekend days. The holidays that are excluded from weekday analyses include:
  1. New Year’s Day
  2. Martin Luther King, Jr. Day
  3. President’s Day/Washington’s Birthday
  4. Memorial Day
  5. Independence Day
  6. Labor Day
  7. Thanksgiving Day (and the day after)
  8. Christmas (and day before or after, depending on day of week)
  9. New Year’s Eve Day

- Fixed and consistent time periods were defined for all cities. These were:
  1. 12:00 am to 6:00 am – early morning
  2. 6:00 am to 9:00 am – morning peak
  3. 9:00 am to 4:00 pm – mid-day
  4. 4:00 pm to 7:00 pm – afternoon peak
  5. 7:00 pm to 12:00 am – late evening
  
- Only mainline freeway detectors were included. Some cities reported ramp data, but these were dropped to maintain consistency across the cities.

**Figure 3. Estimating Directional Route Travel Times and VMT From Spot Speeds and Volumes**



## Congestion Measures

The Mobility Monitoring Program tracks traffic congestion using the three measures below. For most applications, these measures are reported for the peak periods (6 to 9 a.m. and 4 to 7 p.m.):

- **Travel time index** (measures congestion intensity, also congestion duration when shown by time of day)
- **Percent of congested travel** (measures congestion extent, also congestion duration when shown by time of day)
- **Total delay** (measures congestion intensity)

The travel time index is the ratio of average peak travel time to a free-flow travel time (Equation 1). In this report, the free-flow conditions are travel times at a speed of 60 mph. Index values can be related to the general public as an indicator of the length of extra travel time spent during a trip. For example, a value of 1.20 means that average peak travel times are 20 percent longer than free-flow travel times. In this report, the travel time index is calculated for directional freeway sections (as shown in Figure 3), then combined into an areawide average by weighting each freeway section by the respective VMT (Equation 2).

For a specific road section and time period :

**Equation 1**

$$\text{Travel time index} = \frac{\text{Average travel time (minutes)}}{\text{Free – flow travel time (minutes)}}$$

(no units)

For several road sections and time periods :

**Equation 2**

$$\text{Average travel time index} = \frac{\sum_{i=1}^n (\text{travel time index}_n \times \text{VMT}_n) \text{ each section and time period}}{\sum_{i=1}^n (\text{VMT}_n) \text{ each section and time period}}$$

(no units)

The **travel time index** can be applied to various transportation system elements with different free-flow speeds, although only freeways were analyzed in the Mobility Monitoring Program. The index can be averaged for streets, freeways, bus and carpool lanes, bus and rail transit, bicycle facilities, and sidewalks. All of these system elements have a free-flow travel time and when crowded, the travel time increases. In a multi-modal context, the VMT in Equation 2 is replaced with person-miles of travel (PMT). An average corridor value can be developed with the number of persons using each facility or mode to calculate the weighted average of the conditions on adjacent streets, freeways, HOV lanes, bus routes and/or rail transit lines. The corridor values can be computed for certain time periods and weighted by the number of travelers to estimate peak-period or daily index values.

The **percent of congested travel** is calculated as the ratio of congested VMT to total VMT (Equation 3). In this report, a free-flow speed of 60 mph is used as the value below which VMT is considered to be congested.

$$\text{Percent of congested travel (\%)} = \frac{\text{congested VMT}}{\text{total VMT}} \quad \text{Equation 3}$$

Our experience indicates that the use of a 60 mph threshold in the percent congested travel measure may over-represent the magnitude of congestion. In several cities, the spot speeds collected by point-based detectors are less than 60 mph even in light traffic conditions. These point-based detectors are also more likely to record lower speeds than longer distance travel time measurements, due to their common location near entrance ramps and the much greater variation in speed over short sections than long sections. These considerations suggest that a lower speed may be more appropriate for the congestion threshold in this measure when using point-based sensors. Unlike the other congestion measures, congested travel is a binary attribute—travel is either congested or it is not congested, no matter how close the speed is to the congestion threshold. Thus, for a given time period, the VMT is assigned as either congested or not congested, even if the average speeds are just below the congestion threshold. For example, if the nighttime speed limit on an urban freeway system is 55 mph, a significant portion of travel could be categorized as congested without heavy traffic being the cause.

**Delay** is calculated as the additional travel time that is incurred when actual travel times are greater than free-flow travel times (Equations 4 and 5), expressed in this report as vehicle-hours as well as vehicle-hours per 1,000 VMT. The delay measure can also be expressed in person-hours in a multi-modal context where person travel quantities are known.

For a specific road section and time period :

$$\text{Delay (vehicle - hours)} = \frac{\left( \begin{array}{c} \text{Average Travel Time} \\ \text{(minutes)} \end{array} - \begin{array}{c} \text{Free - flow Travel Time} \\ \text{(minutes)} \end{array} \right) \times \text{Traffic Volume (vehicles)}}{60 \frac{\text{minutes}}{\text{hour}}} \quad \text{Equation 4}$$

For several road sections and time periods :

$$\text{Total Delay (vehicle - hours)} = \sum_{i=1}^n \text{Delay}_n \quad \text{Equation 5}$$

## Reliability Measures

The congestion measures in the previous section represent the average and total levels of congestion. In addition to average and total statistics, there is a growing recognition of the need to track variability of congestion and the reliability of travel. The Mobility Monitoring Program tracks these measures for travel reliability:

- **Planning time index**
- **Buffer index**

The **planning time index** is statistically defined as the 95<sup>th</sup> percentile travel time index (Equation 6) and also represents the extra time most travelers add to a free-flow travel time when planning trips. For example, a planning time index of 1.60 means that travelers should plan for an additional 60 percent travel time above the free-flow travel time to ensure on-time arrival most of the time (95 percent in this report).

*For a specific road section and time period :*

**Equation 6**

*Planning time index (no units) = 95<sup>th</sup> percentile travel time index*

The planning time index is useful because it can be directly compared to the travel time index on similar numeric scales. For example, assume that the peak period travel time index for a particular road section is 1.20, which means that average travel times are 20 percent longer in the peak period than during free-flow conditions. Now assume that the planning time index for that same road and time period is 1.60, which means that 95 percent of all travel times are less than 60 percent longer than during free-flow conditions. In other terms, the planning time index marks the upper limit for the nearly worst (95 percent of the time) travel conditions.

The **buffer index** represents the extra time (buffer) most travelers add to their average travel time when planning trips (Equation 7). The buffer index is differentiated from the planning time index in these two important ways:

- The buffer index is expressed as a percentage;
- The buffer index represents the extra time between the average travel time and near-worst case travel time (95<sup>th</sup> percentile), whereas the planning time index represents the extra time between the free-flow travel time and the near-worst case travel time (95<sup>th</sup> percentile).

*For a specific road section and time period :*

**Equation 7**

$$\text{Buffer index (\%)} = \frac{\begin{array}{c} 95^{\text{th}} \text{ percentile travel time} \\ \text{(minutes)} \end{array} - \begin{array}{c} \text{average travel time} \\ \text{(minutes)} \end{array}}{\begin{array}{c} \text{average travel time} \\ \text{(minutes)} \end{array}}$$

For example, a buffer index of 40 percent means that a traveler should budget an additional 8-minute buffer for a 20-minute average peak travel time to ensure on-time arrival most of the time (95 percent in this report). The 95<sup>th</sup> percentile travel time was chosen for these reliability measures to represent a near-worst case scenario. For example, the 95<sup>th</sup> percentile travel time corresponds to a 95 percent on-time arrival rate, which can be simply explained in non-technical terms as “being late for work one day per month.” Other percentiles, such as the 85<sup>th</sup> or 90<sup>th</sup> percentile, could be used in this or other applications. Ultimately, the application of the reliability measure will determine the percentile used in its calculation.

Equations 6 and 7 show the reliability measure calculations for a specific road section and time period. For these reliability measures, the road section and time period should be chosen in a way that accurately represents the reliability of interest. For example, an analysis of urban commuting reliability would likely consider freeway sections 5 to 10 miles in length whose endpoints correspond to major freeway or major arterial interchanges. Alternatively, an analysis of intercity travel reliability would consider much longer freeway sections whose endpoints correspond to popular city origins and destinations. The time period(s) should be selected to include conditions of a similar nature and interest to travelers. For example, a buffer index for a typical commuter audience will likely focus on periods throughout the day in which commute travel is made, and should not mix travel times from these different periods. That is, travel times from the evening peak period should not be combined into the same distribution as the morning peak travel times when calculating a 95<sup>th</sup> percentile.

The average planning time or buffer index values (across several road sections, time periods, etc.) can be calculated by using the VMT as a weighting factor (Equation 8).

*For several road sections and time periods :*

**Equation 8**

$$\text{Average index value} = \frac{\sum_{i=1}^n (\text{index value}_n \times \text{VMT}_n) \text{ each section and time period}}{\sum_{i=1}^n (\text{VMT}_n) \text{ each section and time period}}$$

The Program also tracks throughput using peak-period and total daily VMT, which is calculated as shown in Figure 3.

### **Other Considerations for Performance Measure Calculations**

The performance measure analysis uses data in a standard format, which currently consists of 5-minute data (all times of the day and days of the year) for 5- to 10-mile freeway sections. This standard format corresponds with the bottom part of the diagram in Figure 3. Combining the estimated travel time values or performance measures from each 5-minute time period is accomplished using VMT as a weighting factor for each time period.

Measures that do not use specific origins and destinations generally provide easier comparisons because these measures are length-neutral and can be applied to a wider variety of situations. If

trip-based measures are desired as examples for specific origins and destinations, the performance measures described here can be used with the estimated travel time for a specific trip. This combination of generalized, length-neutral measures as well as specific examples should provide statistics with which most audiences can relate.

There is no single best performance measure and users should resist the urge to select a single measure or index for all situations. Each performance measure reported here addresses different dimensions of traffic congestion or different aspects of reliability. The “dashboard” concept of using a “few good measures” is appropriate, and performance monitoring programs should consider selecting a few (for example, two or three of the five presented here) measures for an executive summary or dashboard report.

This analysis defines fixed-length time periods in which to compute average peak period measures. No single time period will be correct for all analyses, but there are several considerations as follows:

- *Peak hour or peak period* – Transportation engineers have traditionally used a peak hour to describe congestion, but major urban areas now experience slow speeds for multiple hours in both the morning and the afternoon. In many areas, congestion growth occurs in the hours before or after the traditional peak hour. Use of a single peak hour misses the congestion that occurs during other times, prompting many areas to define a multi-hour peak period.
- *Urban area size* – Using a 3- to 4-hour peak period for all area sizes may mask congestion for the smaller urban areas. Smaller areas can probably develop useful statistics with only peak hour analyses.
- *City-to-city comparison* – A consistent peak-period length is necessary for any type of comparison between cities. Comparative studies between urban areas should probably use peak period analyses, rather than only a peak hour.
- *Daily or peak comparisons* – For national comparisons of reliability trends, a day-to-day comparison is appropriate. For local purposes, where individual trip planning is also an issue, it may be useful to also include travel reliability within an hour or for several segments of a multi-hour peak period.

## 4. MAJOR FINDINGS AND CONCLUSIONS

This chapter summarizes the major findings and conclusions from the fourth year of the Mobility Monitoring Program. To date, this Program has gathered and analyzed archived traffic detector data from 2000 through 2003. However, this fourth year provided the first opportunity to analyze more than two years of annual trends for more than 20 cities. Thus the findings are mainly focused on this Program's key objectives of tracking nationwide estimates of traffic congestion and reliability.

This chapter is presented in the form of "frequently asked questions" and as such departs from the normal tradition of a technical report. Our intention is to make the most desired information readily accessible and understandable, as opposed to making readers slog through numerous pages of data tables and charts that simply summarize the data but provide no interpretation or message. The frequently asked questions that are answered in this chapter are as follows:

- Are traffic congestion and/or travel reliability getting worse?
- How does reliability relate to average congestion levels?
- How are the performance measures different, and what does each tell me?

### **Are traffic congestion and/or travel reliability getting worse?**

The short answer is yes, it appears that traffic congestion and travel reliability have gotten worse since 2000, the earliest data gathered for the Mobility Monitoring Program (Table 8). The congestion trends in this study differ among cities but the national estimates generally agree with those reported in the Urban Mobility Report. The four years (2000 through 2003) of archived detector data in the Mobility Monitoring Program point to an overall national trend of steady growth in traffic congestion and decline in travel reliability.

There are, however, several footnotes and caveats that must be highlighted and considered in this same discussion of worsening traffic congestion and travel reliability.

1. *The measurement system is changing every year* – Ideally, trend analyses would be based on a stable measurement system. However, the growth in number of cities as well as the growth in ITS deployment has produced a congestion measurement system that has grown substantially in its first four years. The national estimates in Table 8 address some of the measurement system change by using the same 20 cities that were able to provide data from 2001 to 2003, while dropping year 2000 estimates that only contained 10 cities. However, even in the 20 cities considered in this table, the freeway lane-mile coverage has increased at 11 percent between 2001 and 2003, whereas the total VMT measured in these 20 cities has increased at 32 percent over the same time period. This trend is likely to continue as ITS deployment progresses across the nation.
2. *Several cities appear to have suspect data* – Some charts in the city reports for certain cities have odd or unexpected trends. For example, the data from several cities indicate that congestion and delay is 3-4 times worse in the evening peak period than the morning peak period, or vice versa. Other charts indicate low vehicle speeds during times of

typically light traffic (such as the early morning). Although most performance measures and their trends fall within the range of possibility, the trends in several cities are nearly outside the range of probability. In other words, it is possible but doubtful that some of these trends truly exist, and therefore the data in those cities should be considered suspect.

3. *The national estimates include only freeways where traffic detector data have been collected for operations purposes and then archived* – Traffic detector data are typically collected on the most congested freeways, which may not be a representative sample of areawide freeway conditions. Several cities do have significant freeway coverage—for example, 14 of the 29 cities have more than 50 percent of their freeway lane-miles instrumented with traffic sensors. Across all 29 cities, the average percent coverage of freeway lane-miles is 53 percent (Table 4). Therefore, the actual performance measure values in Table 8 may be slightly high because they reflect the half of the freeway system that is most congested. The trend values are also affected by this coverage issue, as some of the outlying freeway sections that have the fastest congestion growth may not be instrumented with traffic sensors yet.

**Table 8. National Congestion and Reliability Trends**

Measure	Measure Value			Change in Measure Value		
	2001	2002	2003	2001-2002	2002-2003	2001-2003
<b>Mobility Monitoring Program</b> (includes a sample of freeways in 20 cities <sup>1</sup> )						
travel time index	1.24	1.27	1.28	+3	+1	+4
buffer index	19%	20%	20%	+1%	+0%	+1%
delay per 1000 VMT	4.21	4.54	4.75	+8%	+5%	+13%
<b>Urban Mobility Report</b> (includes freeways and arterial streets in 85 cities <sup>2</sup> )						
travel time index	1.36	1.37	n.a.	+1	n.a.	n.a.
delay per peak traveler (hours)	52	52	n.a.	0%	n.a.	n.a.

Notes: <sup>1</sup> The 20 cities included in the Mobility Monitoring Program’s national estimates include Albany, Atlanta, Austin, Charlotte, Cincinnati, Detroit, Hampton Roads, Houston, Los Angeles, Louisville, Milwaukee, Minneapolis-St. Paul, Orlando, Philadelphia, Phoenix, Pittsburgh, Portland (OR), San Antonio, San Diego, and Seattle.

<sup>2</sup> The 85 cities included in the Urban Mobility Report are documented at <http://mobility.tamu.edu/ums>.

Further analyses were performed to test the hypothesis that the 11 percent increase in freeway coverage between 2001 and 2003 affects the trends presented in Table 8. In these analyses, comparisons were made only between those freeway sections that were collecting data from 2001 through 2003, thereby eliminating the effect of increasing freeway coverage. The results of this analysis are shown in Table 9.

We make the following observations from the results in Table 9 (which keeps the freeway coverage constant):

- With regard to average peak period congestion level (travel time index), more freeway sections are getting better than getting worse, but only by a small margin (4 percent).
- With regard to peak period travel reliability (buffer index), more freeway sections are getting better than getting worse, but only by a small margin (3 percent).
- With regard to total delay experienced at all times of the day, both weekday and weekend, more freeway sections are getting worse than getting better, by a relatively large amount (12 percent).

**Table 9. Trends (2001-2003) in Congestion and Reliability at the Freeway Section Level**

National Estimate (20 cities)	Number (%) of freeway sections:		
	Getting worse <sup>1</sup>	No significant change <sup>2</sup>	Getting better <sup>3</sup>
Travel Time Index	151 (31%)	168 (34%)	<b>174</b> <b>(35%)</b>
Buffer Index	174 (38%)	99 (21%)	<b>188</b> <b>(41%)</b>
Total Daily Delay	<b>241</b> <b>(49%)</b>	70 (14%)	182 (37%)

**Notes:** <sup>1</sup> Getting worse means that, from 2001 to 2003, 1) the travel time index increased by 3 or more points; 2) the buffer index increased by 3% (percentage-points) or more; or 3) the delay increased by 10 percent or more.

<sup>2</sup> No significant change means that, from 2001 to 2003, 1) the travel time index changed by less than 3 points; 2) the buffer index changed by less than 3% (percentage-points); or 3) the delay changed by less than 10 percent.

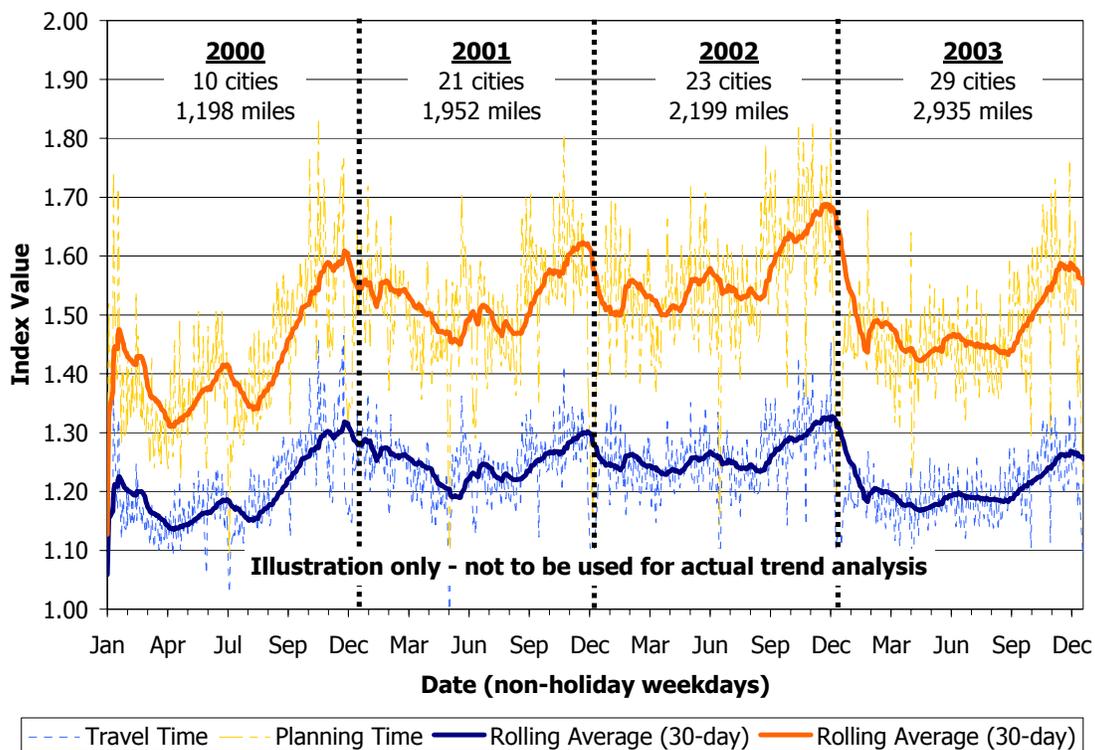
<sup>3</sup> Getting better means that, from 2001 to 2003, 1) the travel time index decreased by 3 or more points; 2) the buffer index decreased by more than 3% (percentage-points) or more; or 3) the delay decreased 10 percent or more.

A possible explanation for the different outcomes for different performance measures in Table 9 is that peak period congestion and reliability may be getting better, but delay during other times of the weekday and weekend have grown considerably. There are small differences (3 and 4 percent) between the percentages getting better and worse for both the travel time index and buffer index, so “no significant change” is also within the margin of error for this type of analysis. The economic conditions between 2001 and 2003 also could have some effect on slightly lower congestion levels.

Table 10 provides detailed results for all cities for all available years of data. This chart indicates that the congestion, delay and reliability trends differ among the cities. For the travel time index, several cities show relatively stable results between 2000 and 2003, such as Detroit, Phoenix, and Seattle. Other cities travel time index values have grown considerably, such as Atlanta and Houston. Still other cities have shown an up-and-down fluctuation over the past three to four years, such as Cincinnati, Los Angeles, and Minneapolis-St. Paul. The buffer index values in Table 10 typically exhibit less fluctuation than the travel time index values, as buffer index values for most cities range between 10 and 20 percent.

Figure 4 illustrates the necessity of keeping the measurement coverage (number of cities and miles of coverage) relatively constant when examining congestion and reliability trends. This figure shows the national day-to-day and rolling averages (30-day) for the travel time and planning time index from 2000 through 2003. The planning time index is shown here with the travel time index because it has the same units (buffer index is reported as percentage) and displays the near-worst case travel time index values. Several observations are made:

- There is a significant amount of day-to-day fluctuation in both the congestion and reliability measures, indicating the importance of including day-to-day reliability as a performance measure.
- Because the chart includes all cities and all available data, it shows the effects of adding freeway coverage, as the trend lines show an abrupt change at the beginning of 2001 when 11 additional cities were added. Also, the trend lines dropped in 2003 when six cities were added (Baltimore, Dallas, El Paso, Orange County (CA), Riverside-San Bernardino (CA), and San Francisco).



**Figure 4. Illustration of Misleading Trends When Measurement Coverage Increases**

**Table 10. Traffic Congestion, Delay, and Reliability Statistics from Mobility Monitoring Program: 2000 through 2003**

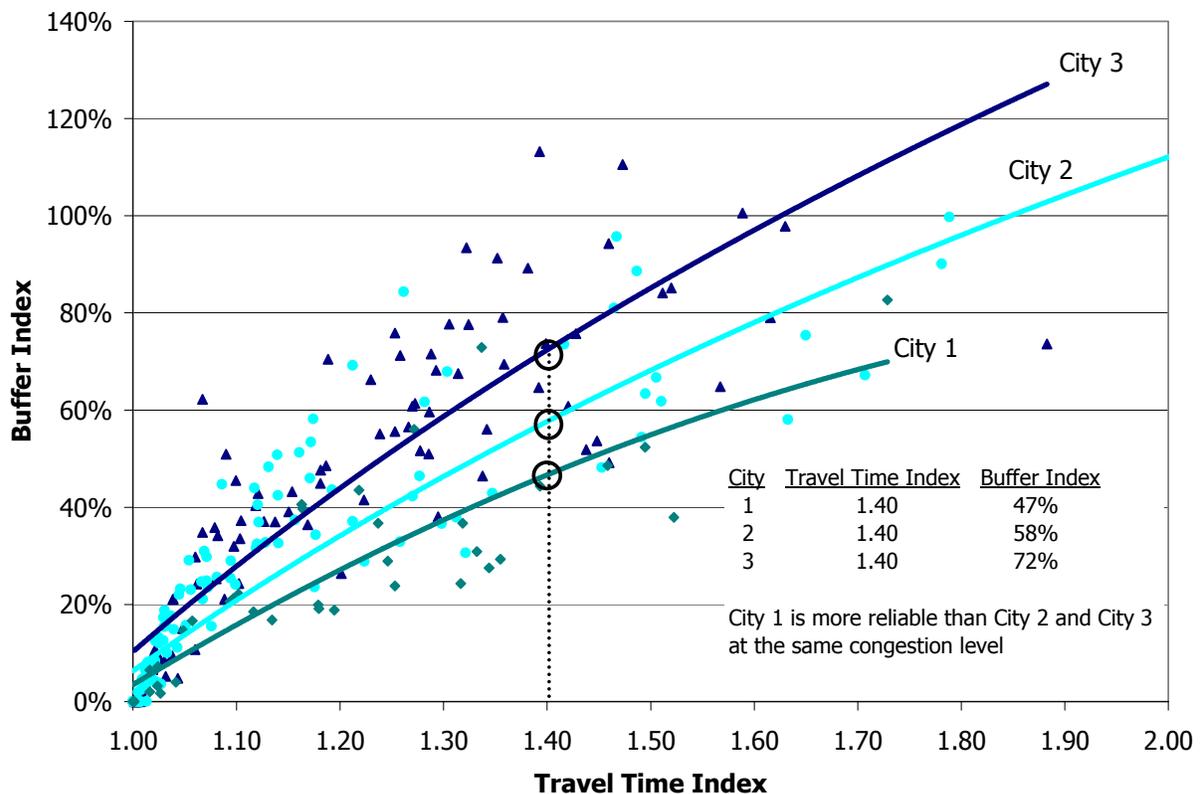
National Estimate	Travel Time Index				Buffer Index				Delay per 1000 VMT			
	2000	2001	2002	2003	2000	2001	2002	2003	2000	2001	2002	2003
20 cities, 2001-2003 data		<b>1.24</b>	<b>1.27</b>	<b>1.28</b>		<b>19%</b>	<b>20%</b>	<b>20%</b>		<b>4.21</b>	<b>4.54</b>	<b>4.75</b>
1 Albany, NY		1.10	1.10	1.11		12%	11%	11%		1.71	1.89	1.98
2 Atlanta, GA	1.14	1.19	1.24	1.24	13%	15%	15%	17%		3.34	3.85	4.22
3 Austin, TX	1.24	1.10	1.10	1.22	20%	14%	14%	18%	4.37	2.49	3.02	4.09
4 Baltimore, MD				1.17				23%				2.96
5 Charlotte, NC		1.23	1.17	1.20		22%	15%	17%		4.10	3.36	3.71
6 Cincinnati, OH/KY	1.23	1.33	1.30	1.29	20%	20%	18%	21%		5.55	5.03	4.09
7 Dallas, TX				1.33				29%				5.34
8 Detroit, MI	1.14	1.12	1.11	1.12	16%	15%	20%	17%		2.21	2.17	2.27
9 El Paso, TX				1.26				12%				2.91
10 Hampton Roads, VA	1.09	1.01	1.07	1.60	18%	4%	13%	32%	1.66	1.01	0.79	8.90
11 Houston, TX	1.17	1.11	1.22	1.29	19%	19%	22%	26%	3.07	3.40	3.78	3.34
12 Long Island, NY		1.39				23%				5.94		
13 Los Angeles, CA	1.39	1.35	1.42	1.43	17%	25%	26%	27%	6.51	5.64	6.55	6.85
14 Louisville, KY		1.15	1.07	1.08		19%	12%	11%		2.36	1.30	1.89
15 Milwaukee, WI		1.07	1.08	1.10		10%	10%	12%		2.07	1.80	1.84
16 Minneapolis-St. Paul, MN	1.21	1.27	1.20	1.23	18%	23%	21%	20%	3.59	4.86	3.78	3.92
17 Orange County, CA				1.14				13%				2.60
18 Orlando, FL		1.34	1.22			18%	22%			5.40	4.96	
19 Philadelphia, PA		1.22	1.22	1.21		20%	18%	19%		3.78	4.01	3.92
20 Phoenix, AZ	1.15	1.15	1.17	1.16	15%	14%	14%	16%	2.63	2.62	2.79	2.60
21 Pittsburgh, PA		1.16	1.23	1.20		10%	16%	16%		3.30	4.05	3.72
22 Portland, OR		1.37	1.33	1.30		20%	20%	16%		6.05	5.55	5.01
23 Riverside-San Bernardino, CA				1.08				6%				1.28
24 Sacramento, CA			1.08	1.16			11%	15%			1.84	3.30
25 Salt Lake City, UT			1.01	1.05			1%	11%			0.41	0.89
26 San Antonio, TX	1.12	1.09	1.09	1.11	16%	13%	14%	15%	2.38	1.81	2.04	2.11
27 San Diego, CA		1.21	1.18	1.19		18%	16%	15%		3.48	3.24	3.03
28 San Francisco, CA				1.12				18%				2.10
29 Seattle, WA	1.28	1.26	1.27	1.26	14%	14%	14%	14%		4.53	4.41	4.22
30 Washington, DC			1.17	1.29			17%	21%			5.85	4.86

**Note:** Blank cells indicate data not available for that city and year.

## How does reliability relate to average congestion levels?

The travel time index values reported through the Mobility Monitoring Program are peak period averages for all non-holiday weekdays. As such, the travel time index values represent average traffic congestion levels when considering weekday traffic. The reliability measures (buffer index and planning time index) represent how the travel time index varies between weekdays. A travel time index that is consistently high (does not vary much during the weekdays) should have a low buffer index. Conversely, a travel time index that varies considerably during the weekdays should have a higher buffer index value. But does the congestion level have a relationship with reliability?

In analyzing the archived data, we have found a fairly consistent relationship between congestion and reliability levels. That is, when the travel time index increases, the buffer index also increases by a corresponding increment. Figure 5 shows an example of the relationship between congestion and reliability levels as seen in the 2003 data. The figure shows travel time index and buffer index values for three cities. A simple regression line has been drawn for the data from each city.



**Figure 5. Exploring the Relationship between Congestion Level and Travel Reliability**

Figure 5 shows that, for comparable congestion levels (travel time index = 1.40), each of the three example cities would have different reliability levels. For example, City 1 has a predicted

“best fit” buffer index value of 47 percent, whereas City 3 has a predicted “best fit” buffer index of 72 percent.

This preliminary finding is important because it implies that it may be possible to improve the reliability of travel even if the congestion level remains the same. We are only beginning to explore the relationship between average congestion levels and reliability. There are numerous factors that affect the reliability of travel, and future analyses will attempt to better understand the relationship of these factors to congestion and reliability levels:

- Inclement weather;
- Work zones;
- Traffic incidents and incident management practices;
- Availability of alternate routes;
- Level of traveler information services;
- Level of ITS deployment and operations activities; and
- “Aggressiveness” of traffic management and operations activities.

### **How are the performance measures different, and what does each tell me?**

There are cases when a single performance measure can be used in a mobility analysis, but most situations can benefit from more than one measure. Mobility measures like the travel time index and reliability measure like Buffer Index are related, but they identify different elements of performance. In many cases, the various measures identify different trends. For example, Table 11 shows the trends for several performance measures for three cities: Cincinnati, Houston, and Pittsburgh.

The following observations are made regarding the trends in Table 11:

- Cincinnati shows declines in congestion levels but worsening reliability conditions. This goes against the general trend seen in most areas, but the changes are relative in both cases. A number of factors could have degraded the reliability while the average congestion level remained the same. Delay per 1000 VMT declines significantly due to the significant rise in peak period VMT.
- Houston shows an increasing travel time index and decreasing delay per 1000 VMT. This could be the result of increases in travel outside of the normally congested times and road sections, since the travel time index measures peak period conditions only and the delay measures is total daily delay. While the congestion levels can increase, travel in the uncongested road sections and times of the day can increase faster because congested sections typically carry less traffic per lane than freeway sections with moderate traffic congestion.
- Pittsburgh saw an increase in congested travel from 2002 to 2003, but a decrease in the travel time index. This may reflect the fact that the definition of congested travel is binary—either a section is congested or it is not congested. The travel time index, conversely, is a continuous measure that reflects average peak period conditions.

**Table 11. Different Performance Measures May Reveal Changes  
in Different Elements of Performance**

Measures	Current Year	Last Year		Two Years Ago	
	2003	2002	Change	2001	Change
<b>Cincinnati, OH-KY</b>					
Travel Time Index	1.29	1.30	-1% ↓	1.33	-3% ↓
Planning Time Index	1.61	1.56	+3% ↑	1.63	-2% ↓
Buffer Index	21%	18%	+3% ↑	20%	+1% ↑
% Congested Travel	67%	71%	-4% ↓	81%	-14% ↓
Total Delay (veh-hours) per 1000 VMT	4.09	5.03	-19% ↓	5.55	-26% ↓
<b>Houston, TX</b>					
Travel Time Index	1.29	1.22	+6% ↑	1.11	+17% ↑
Planning Time Index	1.71	1.55	+10% ↑	1.40	+22% ↑
Buffer Index	26%	22%	+4% ↑	19%	+7% ↑
% Congested Travel	27%	30%	-3% ↓	24%	+3% ↑
Total Delay (veh-hours) per 1000 VMT	3.34	3.78	-12% ↓	3.40	-2% ↓
<b>Pittsburgh, PA</b>					
Travel Time Index	1.20	1.23	-2% ↓	1.16	+3% ↑
Planning Time Index	1.43	1.47	-3% ↓	1.31	+9% ↑
Buffer Index	16%	16%	0% —	10%	+6% ↑
% Congested Travel	55%	50%	+5% ↑	49%	+6% ↑
Total Delay (veh-hours) per 1000 VMT	3.72	4.05	-8% ↓	3.30	+13% ↑

**Note:** Colored arrows represent relative change from a comparison of the current year (2003) to previous years (2001 and 2002).

These examples demonstrate the following key principles for performance measures:

1. There is no single best performance measure for all issues/problems.
2. Each performance measure represents different dimensions of the issue/problem.
3. Performance monitoring programs should include an interpretation that addresses the fact that different performance measures reveal different aspects of the issue/problem.

## **5. RECOMMENDATIONS**

### **Promote Local Use of Archived Operations Data**

In the long run – especially as many more cities deploy TMCs and coverage for existing systems expand – a national performance measurement program will benefit from increased local involvement in archiving and use of operations data. As more local applications are developed, there will be increased pressure to ensure high quality data. Also, much of the initial data processing (quality control and aggregation) can be achieved at the local level, making the national process more efficient.

*Recommendations:* (1) Make archiving and performance measurement a major focus of the Planning for Operations effort. Operations data provide local planners a rich source of information for both traditional and innovative applications, and gives them “something in return” for the extra effort required to integrate operations into planning. (2) Develop 1-2 case studies highlighting how operations and planning agencies work together to achieve performance measurement from their agency perspectives. If appropriate, extend the case studies to encompass how Planning for Operations is achieved. (3) Promote standards and guidelines for data collection, data quality maintenance, performance metrics, and analysis procedures for archived data. (4) Document the differences in methods for developing performance measures (modeling, floating cars, roadway detectors, probe vehicles, cell-phone tracking); identify adjustment techniques to make them compatible.

### **Presentation and Use of Performance Measures in Decision-Making**

As discussed earlier, identification of which performance metrics (measures) should be used in a congestion monitoring program has received a good deal of attention over the past few years. The remaining three pieces of the performance measurement process are: What data are needed? How should the measures be presented? And, how should the measures be used in the decision-making process? This next step deals with the second and third of these issues. The toughest of these two issues is how performance measures influence investment and policy decisions.

*Recommendations:* (1) A scan should be conducted of different methods being used by transportation agencies to present congestion performance measures to the public and decision-makers. From this, a compendium highlighting the most effective presentation methods should be compiled. (2) Case studies of two or three transportation agencies that have aggressive congestion performance monitoring programs in place should be conducted to document how the measures have influenced investment and policy decisions.

### **Improve Traffic Detector Data Quality at Its Source**

A high level of data quality is absolutely essential for an archive to be useful to a wide variety of interests (including performance measurement). If users perceive that the data are not of sufficient quality, the archive will not get used and interest will wane. The best way to ensure quality data is to have the original collectors (owners) use it for their own benefit. For example, the traffic management centers should use this information for planning their activities,

deploying operational forces, programming maintenance efforts, etc. Improving data quality also includes developing formal review procedures (which can be automated through software), routinely publishing data quality statistics, and establishing a feedback process whereby users can alert collectors/owners of quality problems not originally detected. However, that is the easy part. A much more difficult part of maintaining a high level of data quality is ensuring that field devices are properly installed, calibrated, and maintained. These activities require significant investment by data collectors/owners.

*Recommendation:* Document the costs of proper detector installation, calibration, and maintenance activities, especially with regard to type of equipment and the level of data quality (accuracy in the field measurements) achieved. Identifying best practices for each of these activities would also foster archive development and use. Promoting the use of quality control software by data collectors/owners (i.e., traffic management centers) would also support maintenance of quality data. Document the implications on performance measures of sparse detector coverage as well as poor data quality.

### **Integrate Event Data at the Local Archive Level**

The congestion performance measures developed so far focus mainly on an overall picture of congestion using traffic detector, probe, or modeled data. However, to be more useful for implementing operations strategies, the causes of congestion should be tracked at a detailed level. In other words, what factors (“events”) have contributed to overall mobility and what are their magnitude; factors include traffic incidents, weather, work zones, changes in traffic demand, special events, and recurring bottlenecks. If the share of total congestion attributable to these sources can be produced, strategies targeted at the root causes can be developed. Identifying the events that are restricting mobility is important at both the national level (development of overall programs) and the local level (development of specific actions). Key in this effort is the capture of roadway event-related data in a consistent manner. These data must be fully integrated with traffic detector and other forms of traffic data so that the events’ influence on congestion patterns can be ascertained.

*Recommendations:* (1) An effort should be undertaken to harmonize the data requirements required for documenting roadway events from performance measurement and archive perspectives as opposed to purely an operational perspective. This involves review of and potential modification to existing ITS standards and standards used in the data systems of non-transportation agencies (especially police computer-aided dispatch systems). (2) A scan of current event/traffic data integration practices among ITS data archives would reveal best practices and potential pitfalls.



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