Monitoring Urban Roadways in 2000: Using Archived Operations Data for Reliability and Mobility Measurement

Submitted to

Federal Highway Administration
Operations Core Business Unit

Tim Lomax
Shawn Turner
Texas Transportation Institute
The Texas A&M University System
College Station, Texas

Richard Margiotta
Cambridge Systematics, Inc.
Knoxville, Tennessee

December 2001

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-OP-02-029		

4. Title and Subtitle	5. Report Date
Monitoring Urban Roadways in 2000: Using Archived Operations Data for Reliability and Mobility Measurement	December 2001
	6. Performing Organization Code
7. Author(s) Tim Lomax, Shawn Turner and Richard Margiotta	8. Performing Organization Report No.
9. Performing Organization Name and Address Texas Transportation Institute 3135 TAMU College Station, TX 77843-3135 Cambridge Systematics, Inc. 5225 Wisconsin Ave., N.W. Washington, DC 20015	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address US Department of Transportation Federal Highway Administration Operations Core Business Unit Washington DC 20590	13. Type of Report and Period Covered Interim: January 2000 – December 2000 14. Sponsoring Agency Code HOTM-1

15. Supplementary Notes
Project COTR: Mr. Vince Pearce
Research Project Title: Evaluation of Travel Time Methods to Support Mobility Performance Monitoring

16. Abstract

The report summarizes the processes and products from a study of the real-time traffic data generated from the Transportation Operations Centers (TOCs) in 10 cities in 2000. Automatically collected data was analyzed for data quality and completeness and a database prepared for the sections of instrumented freeway. The database format consists of traffic volume, lane occupancy and speed records for every freeway section for each 5-minute period of the year. Other inventory information such as section length, number of lanes, detector type and other characteristics were also collected.

Several mobility and reliability measures were produced – all are based on travel time concepts. They examine the level of travel delay and mobility, as well as the variation in travel conditions from day-to-day through the year and between roadways in urban areas. A variety of illustration techniques and statistical analysis methods are included in the main report. An appendix was created for each city to show ways to provide detailed summaries of average and unusual conditions for corridors and the system.

Current practice emphasizes the real-time uses of the data for operations purposes but, in many cities, does not include extensive use of the data for other purposes. If the products from real-time databases assist operators and planners, there will be more interest in making the effort to create and improve the data collection process and the databases.

17. Key Word	18. Distribution Statement
Archived data, Transportation planning, Operations data, Databases, Mobility, Reliability	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	47	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Acknowledgments

The authors acknowledge the following agencies that participated in the first year of the Mobility Monitoring Program:

Atlanta: Georgia DOT
Cincinnati: ARTIMIS and Kentucky Transportation Cabinet
Detroit: Michigan DOT
Hampton Roads: Virginia DOT and Virginia Transportation Research Council
Houston: Texas DOT and Houston office of Texas Transportation Institute
Los Angeles: Caltrans and University of California at Berkeley
Minneapolis-St. Paul: Minnesota DOT
Phoenix: Arizona DOT
San Antonio: Texas DOT
Seattle: Washington State DOT and Washington State Transportation Center

Disclaimer

Summary – 2001 Mobility Monitoring Program

The first year of the Mobility Monitoring Program included the development of basic procedures and processes that can be used as a framework for mobility and reliability analyses in future years. Data from transportation operations centers in 10 cities were used to develop and test the procedures. The data were gathered from instrumented freeway sections for as much of calendar year 2000 as was available. (See the study website for individual city reports: http://mobility.tamu.edu/mmp). The goal was to develop and apply practices for data checking and quality control, and to produce a database and summary of annual operations for several levels of the system that could be useful to both technical and general audiences.

Project Activities

The data storage and analysis functions can be considered part of the archived data user service (ADUS) within the National ITS Architecture. Many cities are pursuing some variation of the functions encompassed within this user service, but the implementation of such functions in a center devoted primarily to operations is not easy. The Mobility Monitoring Program was able to combine the data and expertise at the local centers with a national perspective on database development and performance measures to investigate a variety of issues that these and other areas will face in the future.

The study team contacted operations and planning groups in each area, met with and discussed the local approach to data archiving, local analysis processes and measures, and identified the standards and guidelines used in the performance measurement process. Local involvement in this effort was very important—both to obtain the best data and information about the system, as well as to encourage local use of the resulting data and measures. Performance measures may only be as good as the data that go into them, but the relationship is circular—the data are also only as good as the people and programs that use the measures need it to be.

In the course of first-year project activities (since mid-1999), the study team has identified many areas that are saving data in some form, but very few that are using the data to create information beyond a real-time operations application. The procedures and measures described in this report provide a framework that will allow many other areas to move more quickly toward broader use of archived operations data for congestion monitoring.

The significant elements and findings of the project can be described in three areas: data collection and database development, performance measure development, and future issues. From the Mobility Monitoring Program's first year (year 2000 data), the following points stand out as those that either should be noted by other cities as they embark on such a program, or should be considered by the technical community as good practice.

Data Collection and Database Development Issues

There was a range of data collection technologies and practices, operating and archiving policies, and institutional arrangements in the 10 cities included in the first year. A few conclusions can already be drawn about some important issues.

- **The archived data quality and completeness varied from excellent to poor for the purposes of mobility monitoring –** The areas that are using the archived data for local transportation analyses typically had much higher quality data than those areas that simply archived and did not use their data. In areas where archived data sets were incomplete, lack of adequate maintenance for traffic sensors and/or communications infrastructure was the often the major cause.
- **In most areas, local analysis of archived data has been a daunting task –** Many data archiving systems are still considered "first generation," in which data is logged to an extremely large text file or thousands of smaller text files that are not readily accessible or usable by most data users. Plans are underway in many areas to improve the accessibility and ease of use of archived data.
- **There are no clear findings regarding the optimum type of traffic sensor for mobility monitoring –** Whatever sensors are used should be able to accurately measure speed or travel times and vehicle volumes at a relatively frequent spacing (0.5 to 1.0 mile). Accurately estimating spot speeds (and then travel times) from single loop detectors is problematic without adding special field hardware or using sophisticated software and estimation procedures. Vehicle probe systems (such as the AVI system in Houston) also present challenges for accurately estimating vehicle volumes for short time periods.
- **The data collection systems in each area produce different patterns and statistics –** These could be misinterpreted as real differences in the transportation systems, when they are merely a function of the data collection devices. Some of these are easily understood such as the difference between point detector speed estimates and roadway link travel times. Others that result from radar, single loops or double loops, or from data stored in a per-lane format or for the total road cross section are not well understood.
- **Speed estimation equations can be improved –** Several speed estimation procedures have been developed for use with single loop detectors, some of them very sophisticated. These might include time-of-day changes, traffic composition changes or other traffic-adaptive procedures. The complexity, however, has been a hurdle for implementation. Some cities were not aware of the speed estimation procedures in their system because they were embedded in the software and not clearly documented.
- **The professional capacity is not yet present in most agencies to take advantage of the information that can be derived from archived data systems –** The data are not readily accessible, the quantity of data can be daunting and analysis techniques are not yet user-friendly. Training can solve some of these needs, but exposure to the benefits of using the data should significantly expand the interest in developing and attending training courses.

Performance Measure Development

Using the data to create measures that transportation professionals and general audiences find valuable has only begun, but some issues were addressed in the study that should be recognized as the practice expands.

- **Until more complete coverage is available, use the data to study local and national trends, but not to develop city level mobility rankings –** Continuous (24 hours per day, 365 days per year) monitoring data provides more insight into important mobility trends (e.g., the relative magnitude of weekend and off-peak congestion, the effect of incidents, etc.) than has ever been possible. These issues have been noted by the profession but were previously not well quantified due to the lack of data. **Until sensor coverage is more complete, however, the archived data may not be useful for between city comparisons**. Trend and individual facility analyses can be effectively performed where data is relatively complete after a few years. Instrumented data coverage and data consistency vary widely among cities—these would affect any conclusions about between-city comparisons.

- **Time-of-day, day-of-year, corridor sections and reliability comparisons are significant benefits of archived data –** These can provide enormous insight to the system operators and users, and are relatively easy to create. They can assist in monitoring congestion levels, programming improvements, scheduling maintenance operations, deploying staff and justifying investments in operations.

- **The system performance data derived from operations may be significantly different from other estimates or modeling efforts –** Combining archived operations data with other data sources should be conducted only where the differences in each type of data are well understood, and where the need for a combination of data is unavoidable. Many issue or corridor analyses can be conducted with the portion of the network that is instrumented, and broader area comparisons can be accomplished with other data sources. For this study, the year 2000 operations data were compiled and made available much more quickly than data from other sources. There will also be differences in measures developed from full-time data collection devices and periodic studies or estimates.

- **Traffic management operators have different data requirements than other archived data stakeholders.** Traditional traffic management strategies, such as incident management, ramp metering, and identification of major queues, do not require the same level of resolution in performance data as trends monitoring. Many of the systems were developed to identify significant breakdowns in traffic flow rather than subtle differences. The question is usually framed as: "are speeds 60 mph or 20 mph?" rather than, "are speeds 38 mph or 33 mph?" As operation strategies become more sophisticated (e.g., more refined traveler information is developed), this may change, but existing systems are more geared to getting a coarse understanding of system performance.

<u>Beyond the First Year – Summary of Future Issues</u>

The first-year efforts have led to the development of a set of measures and best practices for mobility monitoring. Both the methods that should be used and the issues or elements that need improvement have been identified. The major recommendations are:

- **Significantly enlarge roadway sensor coverage and experiment with data sources –** More data should be available from the freeway system, and data from the arterial street network must be added to get a complete picture of the mobility provided by the roadway system. A variety of sensors or data collection technologies are being used and should be monitored over the next few years for improvements. Transit operating data should be added to get a more complete system picture. For total coverage, some measures of walking and bicycling might be added, but it is likely these will not be available through traditional operations programs.

- **Ensure that traffic monitoring data collected by roadway sensors are archived and made available –** Publicity about data collection from operations has made this less of a problem than in the past, but there are a variety of roadway sensor types and systems. Not all of these systems have been connected to an archiving system or been available in formats that a wide range of users can access them.
- **Encourage the local use of the archived data –** Improvement in data and measures will ultimately hinge on local developers and users exploring the range of benefits of archived data systems. Archived data quality and completeness will improve quickly if those responsible agencies are benefiting from the data for preparation of congestion management system reports and other products.
- **Publicize the companion Best Practices guide –** While some elements of the process are still evolving, there are many parts of the mobility monitoring process that are described here and can be implemented. A companion document to this report describes such steps as data collection, data quality assurance, database preparation, and measurement calculation have been concisely described. A core set of procedures can also be adapted for individual city or agency variations.
- **Improve the calibration and maintenance of data collection equipment –** Data "outages" ranged from 21% to 93% in the 10 cities studied. Some of the missing or inaccurate data are easy to detect and fix, others are difficult due to either the nature of the outage or the archiving procedures.
- **Add "event" databases –** Incidents, weather and work zone locations have significant impacts on roadway travel times and can explain many of the unusual results. They can also be used to identify the elements of congestion and unreliability that might be affected by various improvement programs.

Table of Contents

List of Exhibits

1. Introduction

As automated data collection in transportation operations becomes a more familiar part of the urban data landscape, it will be increasingly important to develop procedures that allow easy access to the information. This report summarizes one such effort undertaken on data collected during the year 2000 for parts of the freeway system in 10 U.S. cities. Additional information is available on the study website: http://mobility.tamu.edu/mmp.

The report shows that the information from operations-based traffic monitoring systems can be used to evaluate system performance and user experiences in terms of travel time and its reliability. A variety of measures are used to convey these concepts. Presenting the measures and information in an easy-to-understand format—such as was developed for this report—should encourage traffic management center operators and other state and local agencies to invest time and effort in creating and maintaining archived operations databases. Known as the “archived data user service (ADUS),” the data storage and analysis functions will be the foundation for future monitoring programs in the urban areas and on the roadways they cover.

The products presented in this report should help show that the information can be useful in a variety of ways. Technical and professional level staff can evaluate and “sell” the components of archived data systems that make the most sense for the public and decision-makers in their area. A common database format, discussions of the best practices for a variety of data archiving and analysis processes, the various measures that can be developed, and a framework for collecting and using the huge amount of information will help move data archiving systems forward in the studied areas as well as in other locations.

The report is oriented toward comparisons of mobility and reliability statistics from year-to-year in individual cities. A few comparisons between cities are also presented, but more for an investigation of the presentation measures and issues, rather than as a comparison of traffic conditions in each area. Only data for the portion of the freeway system that is covered by operations-based traffic monitoring equipment is included in the study, so it is not possible to make an accurate comparison of freeway conditions between the cities. In addition, the interviews and research conducted as part of this study consistently showed that management center operators and staff from other state and local agencies value the ability to track individual area changes from year-to-year. Comparisons between areas are less valuable as evaluation tools, although there will eventually be some value when a greater portion of the travel in an area is included in the database. Satisfying the local priorities will go a long way toward improving the quality of data available to the full range of users.

The report consists of five additional chapters.

- Chapter 2 – The Issues—a brief summary of key issues.
- Chapter 3 – The Data—collection, processing, storage and analysis procedures.
- Chapter 4 – The Measures—the measures that were calculated.
- Chapter 5 – The Results: What do the Measures Show….?—a summary of findings from the data.
- Chapter 6 – The Future: Additional Opportunities—expanding the study beyond the first year.

2. The Issues

Several issues that cut across the subject of using archived operations data for transportation system performance evaluation were investigated during the project. A brief summary is presented below to provide a framework for the report.

Mobility and Reliability

Mobility and reliability can be thought of as the two key attributes that are being evaluated. How easy is it to move around, and how much does that "ease of movement" vary? There are typically four components of mobility or congestion:

- Time of day mobility—the amount of time that the transportation system is congested or the mobility provided at various times of the day (e.g., duration).
- System mobility—the amount of the system that is congested or the level of mobility that the system provides (e.g., extent).
- Personal mobility or amount of people traveling in congested conditions—the level of mobility or congestion at the individual traveler level (e.g., intensity).
- The variation in those three—the amount of extra time that has to be built into trip planning so that travelers or goods will arrive on time (e.g., reliability).

Why Collect and Analyze Such Large Datasets?

Some in the profession have suggested that the amount of archived operations data is overwhelming. The procedures documented in this report are targeted to that audience. The procedures consist of an automated analytical process that provides information to a broad range of users and customers. The report and the other products are based on satisfying the needs of the range of potential audiences and users of the information, and the uses they have for data.

The Mobility Monitoring Program Framework

The benefits of developing, using and maintaining an operational data archiving system to support data analysis are a product of a long-term view. The framework of the Mobility Monitoring Program analytical process allows for local standards and issues to be incorporated, while benefiting from the cumulative experience of the range of users and to have a view of the broader applications for the information that can be developed. Having a view of the "market" for information not only provides structure to the program, it provides justification and motivation for improvements.

System Measures and User Experience Measures

Most operations-based data collection systems give relatively direct information about the four mobility/congestion components (i.e., duration, extent, intensity, variability). The data collection systems do not, however, give as direct an indication about the trip-level experience of travelers.

The trip level information can be estimated, however, through a combination of modeling, surveys and automated data collection techniques. The advantage of this approach is that the automated data collection can continuously monitor the areawide road network for many different uses and it can be calibrated to the user experiences with the surveys. Having a framework for integrating various data sources allows each source to be used according to its best application, and does not put undue pressure on data sources to provide information that they/it are not capable of supporting. Both system performance and user experience measures should be tracked because there are audiences for both types of measures and some of the statistics can be produced from the same database.

Data Elements and Analytical Processes Used in the Mobility Monitoring Program

A summary of the data elements and analytical procedures is provided to orient the reader to the level of detail and the scope of the Program. Other data that might also be relevant and useful, but which was not collected (e.g., vehicle occupancy information) is also identified to indicate possible improvements in future reports.

3. The Data

How Were the Data Collected?

The study relied on operations data archived at each of 10 traffic management centers (TMCs) as the source of the data. For all of the cities except Houston, the data were collected at point locations using a variety of technologies including single- and double-inductance loops, radar, passive acoustic, and video image processing (some areas use multiple technologies; see Exhibit 3-1.) These technologies establish a small and fixed "zone of detection" and the measurements are taken as vehicles pass through this zone. For Houston, travel times collected via their automatic vehicle identification (AVI) system were used. This system detects vehicles with toll tags and provides a direct measurement of travel time.

Exhibit 3-1. Summary of Archived Operations Data Collection and Reporting

Participating Urban Area	Data Collection Technology	Average Sensor Spacing	Speed Derivation Method	Submitted Data	
				Roadway	Time Interval
Atlanta, GA	Video image processing	0.4 mi	Direct measurement	By lane	15-minutes
Cincinnati, OH/KY	Mainly single inductance loops; some video and radar	0.5 mi	Estimated[1]	By direction	15-minutes
Detroit, MI	Double inductance loops	2.0 mi	Direct measurement	By lane	1-minute
Hampton Roads, VA	Double inductance loops	0.5 mi	Direct measurement	By lane	2-minutes
Houston, TX	Regional AVI (probe readers)[2]; limited double inductance loops	2.8 mi	Direct measurement	By link	Individual vehicle travel time
Los Angeles, CA	Single inductance loops	0.5 mi	Estimated[1]	By direction	5-minutes
Minneapolis-St. Paul, MN	Single inductance loops	0.5 mi	Estimated[1]	By lane	5-minutes
Phoenix, AZ	Double inductance loops; some passive acoustic detectors	0.3 mi	Direct measurement	By lane	5-minutes
San Antonio, TX	Mainly double inductance loops; some acoustic detectors	0.5 mi	Direct measurement	By lane	20/30-seconds
Seattle, WA	Single inductance loops	0.4 mi	Estimated[1]	By lane	5-minutes

[1]Calculated using volume and occupancy measurements; formulae vary from city to city
[2]Volumes were estimated from AADTs provided by TXDOT

Data collection and processing procedures have been developed individually and the details of the archiving vary from site to site. However, there are several procedures that are common to all sites. In general, the process works as follows for each city (with Houston being slightly different):

- Data are collected by field sensors and accumulated in roadside controllers. These field measurements are by individual lane of traffic. At 20-second to 2-minute intervals, the roadside controllers transmit the data to the TMC.
- Some areas perform quality control (QC) on original data, but this screening is simple and based on minimum and maximum value thresholds.
- Areas that use single inductance loops as sensors can measure only volumes and lane occupancies directly. In these cases, algorithms are used to compute speeds from volumes and occupancies. The algorithms vary from site to site.
- Internal processes at the TMC aggregate the data to specified time intervals for archival purposes. These 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.
- The aggregated data are then stored in text files or databases unique to each TMC. CDs are routinely created at the TMCs to offload some of the storage burden and to satisfy outside requests for the data.

Calibration and maintenance of field equipment and communications are universal problems. The main impediment is lack of resources to devote to these tasks; TMC 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 speed/travel time estimates. (This philosophy may be changing as a result of more stringent data requirements for traveler information purposes, e.g., TMC-based posting of expected travel times to destinations using variable message signs. However, we found the current data resolution used by TMCs 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 loops are known to be producing erroneous or no data. The problem is exacerbated where loops are used because most agencies are reluctant to shut down traffic on heavily traveled freeways just for loop repair. This is not to say that faulty loops 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 sensors is done periodically but no standardized procedures are used across all areas. 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. Bearing in mind that TMCs 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.

Data Elements

For the cities collecting data at specific points on the highway (the nine excluding Houston), the same basic data are archived:

- traffic volumes – the number of vehicles moving through the zone of detection during the specified time period.
- lane occupancy – the percent of time that the zone of detection is "occupied" by a vehicle.
- speed – the average speed of vehicles moving through the zone of detection. Speeds may be directly measured or calculated from volume and occupancy, depending on the technology used. In the aggregation process, some TMCs use just a simple average while others weight the average speed by volume; the latter is more correct for mobility monitoring purposes.

In addition to these primary data elements, other data elements are common to all the TMCs:

- date of the measurement.
- time – either the beginning or ending time for the measurements.
- location – a unique identifier for each sensor is provided. This identifier is composed of data linking a detector to a specific route, direction of travel, milepost or cross-street, and lane number. Location data were typically supplied in supplemental files to the data archives.

Some areas also provide descriptive information about the aggregation process, for example, the number of records that went into an aggregated statistic. Seattle also provides information about the quality of the data, as discussed in the next section.

The resulting datasets are very large. Although they have relatively few data elements, they have tens of millions of records (i.e., "not very wide but extremely deep").

Data Quality

Seattle is the only city that provided information on the quality of the data. A series of detailed QC procedures have been developed by the University of Washington's Transportation Center (1) and the data are flagged as: "bad," "suspect," "good," or "loop disabled." The Mobility Monitoring Program team also developed QC procedures for use in this project. Prior to analysis, data from the cities are subjected to these basic quality control procedures. Data checks for the following conditions are made:

- Maximum volume threshold (greater than 250 vehicles per lane for 5 minutes)
- Maximum occupancy threshold (greater than 90 percent for 5 minutes)
- Maximum speed threshold (greater than or equal to 100 mph)
- Minimum speed threshold (less than 3 mph)

- Sequential volume test (if the same volume is reported for 4 or more consecutive time periods, assume that the detector is malfunctioning)

In some areas, slightly different variations of these thresholds were used based upon input from participating local agencies. If records fail these QC checks, they are flagged and not used in subsequent analyses. The results of the QC process appear in Exhibit 3-2. Note that the percentages are based strictly on the data that were received from the cities.

Clearly, these checks are rudimentary and much remains to be done in the area of quality control. More sophisticated procedures would examine such conditions as:

- Rapid fluctuations in values across successive time periods;
- Lane detectors from the same highway location exhibiting widely different values;
- Detectors from multiple locations reporting the same values (indicative of a system problem)
- Reported values that are widely different from the site's history for similar days of the calendar.
- Incongruence of traffic data values (mean speed, volume, occupancy) for the same record or observation with traffic flow theory.

The Project Team hopes to explore these items in the second year (2001 data) of the Program.

Exhibit 3-2. Summary of Archived Operations Data Quality in 10 Urban Areas

Participating Urban Area	Average Percentage of Records Passing Quality Control Tests (%)[1,2]	
	Volume records	Speed records
Atlanta, GA	89%	89%
Cincinnati, OH/KY	93%	93%
Detroit, MI	99.7%	99.7%
Hampton Roads, VA	91 %	91 %
Houston, TX		
- detectors (Dec. 2000 only)	99.0 %	94.7 %
- AVI system	n.a.	96 % (for travel time)
Los Angeles, CA	n.a.[3]	n.a.[3]
Minneapolis-St. Paul, MN	99.9 %	87 %
Phoenix, AZ	94 %	84 %
San Antonio, TX	99 %	99 %
Seattle, WA	100%	100%

Notes: [1]Quality control was performed on original data as submitted, which varied from 20 sec. to 15 min.
[2]Percentage of records based upon the average across all days of the year 2000, or as otherwise noted.
[3]Quality unknown. Caltrans/University of California at Berkeley provided summary data at the directional facility level in lieu of providing raw detector data.

The other aspect of data quality is data completeness. Data completeness refers to the number of data values we expect compared to the number of actual values. As an example of data completeness, consider the following. 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). Exhibit 3-3 summarizes data completeness for the 10 urban areas. The second and third columns show the percent complete for the original data (time intervals varied from 20 seconds to 15 minutes) that were submitted. It should be noted that the percentages in these columns do not include detectors that did not "report" any records during an entire day; thus, this percentage captures the short-term hardware/software or communication failures of data collection and archiving equipment that may occur sporadically throughout the day. The fourth and fifth columns show the percent complete for processed data. This percentage includes the short-term and long-term equipment failures, as well as removal of data due to failed quality control tests. These statistics show the percentage of data that were actually used in the analysis; the base used in computing the percentages was all detectors in an area times the number of time periods in the year.

Exhibit 3-3. Summary of Archived Operations Data Completeness in 10 Urban Areas

Participating Urban Area	Average % complete of original data as submitted[1,2]		Average % complete of processed data[2]	
	Volume records	Speed records	Volume records	Speed records
Atlanta, GA	81%	81%	72%	72%
Cincinnati, OH/KY	42%	42%	38%	38%
Detroit, MI	67%	65%	67%	65%
Hampton Roads, VA	67 %	48 %	48 %	36 %
Houston, TX				
- detectors (Dec 2000)	75 %	56 %	16 %	19 %
- AVI system	n.a.	n.a.	n.a.	92% for travel time
Los Angeles, CA	n.a.[3]	n.a.[3]	n.a.[3]	n.a.[3]
Minneapolis-St. Paul, MN	94 %	n.a.	93 %	87 %
Phoenix, AZ	78%	78%	74%	37%
San Antonio, TX	76%	62%	64%	62%
Seattle, WA	83%	83%	83%	83%

Notes: [1]The time intervals for original data as submitted varied from 20 seconds to 15 minutes.
[2]Percentage of records based upon the average across all days of the year 2000, or as otherwise noted.
[3]Completeness unknown. Caltrans/University of California at Berkeley provided summary data at the directional facility level in lieu of providing raw detector data.

Data Analysis: Pre-Processing

With the exception of Houston, which reported travel times collected with their AVI system, data from the cities consisted of spot speeds. Because the performance metrics are based on travel time, the first step in the analysis process is to derive travel times from the spot speeds. This was done 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". Vehicle-miles of travel (VMT) were also computed in this way. Other aspects and definitions used in pre-processing the data were:

- Holidays were excluded from analysis. Future analyses may consider holidays separately or as part of weekends, but holidays were felt to be atypical of normal travel patterns.
- Consistent time periods for all cities were defined for analysis. These were:
    - ♦ 12:00 am to 6:00 am – early morning off-peak
    - ♦ 6:00 am to 9:00 am – morning peak
    - ♦ 9:00 am to 4:00 pm – midday off-peak
    - ♦ 4:00 pm to 7:00 pm – afternoon peak
    - ♦ 7:00 pm to 12:00 am – late evening off-peak
- Morning and afternoon peak hours were defined as 7:00 am to 8:00 am and 5:00 pm to 6:00 pm, respectively.
- Only mainline freeway detectors were included. Some cities reported ramp data, but these were dropped to maintain consistency across the cities.

Development of the Metrics

The Travel Time Index is the primary metric that is used in the Mobility Monitoring Program (more detail on the metrics is provided in the next section). The reliability metrics were developed based on the Travel Time Index. That is, reliability is defined in terms of how the Travel Time Index varies over time. In computing summary statistics, VMT-weighted average Travel Time Indices are used rather than straight averages.

4. The Measures

Data for travel time-based measures can be collected directly or estimated as part of many analysis processes currently used. The ultimate implementation of a set of time-based mobility measures in most urban areas will probably rely on some estimation procedures as well as an evolution toward a significant archived operations database. This section describes the measures that form the basis for the mobility and reliability analyses. Included in the measures are the data items that can be gathered from real-time data collection systems.

Mobility Measures

Three primary mobility measures were selected for tracking with the 2000 data. The measures provide information about user experience as well as system operating condition. The limited nature of the system and travel coverage means there are some caveats that must be applied to any interpretation of the statistics. This test phase also provides an opportunity to examine the measures, the calculation procedures and the interpretation.

Delay per person (in person-hours per year) is used to reduce the total travel delay value to a figure that is more useful in communicating to non-technical audiences. It normalizes the impact of mobility projects that handle much higher demand than other alternatives. Delay for the primary route or road in these alternatives may be higher due to this higher volume, but this also indicates the need to examine the facilities or operations included in the “before” case. In this 2001 report (using year 2000 data), delay per person has relatively little meaning due to the lack of a complete roadway monitoring system.

$$\begin{array}{c}\text{Total Delay}\\\text{(person - hours)}\end{array} = \left[\begin{array}{c}\text{Actual}\\\text{Travel Time}\\\text{(minutes)}\end{array} - \begin{array}{c}\text{Acceptable}\\\text{Travel Time}\\\text{(minutes)}\end{array}\right] \times \begin{array}{c}\text{Person}\\\text{Volume}\\\text{(persons)}\end{array} \times \frac{\text{hours}}{\text{60 minutes}} \qquad (1)$$

$$\begin{array}{c}\text{Annual}\\\text{Delay per Person}\\\text{(hours)}\end{array} = \frac{\begin{array}{c}\text{Total Delay}\\\text{for all Weekdays}\end{array}}{\text{Est. Population of Urban Area}} \qquad (2)$$

Travel time was obtained directly from the Houston data collection method and was estimated from point speed detection devices for the other nine cities. Chapter 3 contains more details about data collection and processing.

Travel time index (TTI) is a comparison between the travel conditions in the peak period to free-flow conditions. It uses the units of travel rate due to the ease of mathematical calculation and due to the data elements included in the MMP database. The TTI could also use direct travel time comparisons for trips of the same length. Equation 3 presents the calculation of the travel time index. The measure was also used in the 2001 Annual Mobility Report (*2*) using an estimation process. The travel time index is also similar to the travel rate index (TRI) used in the Annual Mobility Report. The TRI only includes the effect of recurring congestion, while the TTI includes recurring incident congestion—the conditions measured with continuous data collection equipment.

$$\text{Travel Time Index} = \frac{\left(\dfrac{\text{Freeway Travel Rate}}{\text{Freeway Free-flow Rate}} \times \text{Freeway Peak Period VMT}\right) + \left(\dfrac{\text{Principal Arterial Street Travel Rate}}{\text{Principal Arterial Street Free-flow Rate}} \times \text{Principal Arterial Street Peak Period VMT}\right)}{\left(\text{Freeway Peak Period VMT} + \text{Principal Arterial Street Peak Period VMT}\right)} \quad (3)$$

The index can be applied to various system elements with different free-flow speeds, although only freeways were analyzed in the 2001 MMP report. The travel time index in Equation 3 compares measured travel rates to freeflow conditions for any combination of freeways and streets. Index values can be related to the general public as an indicator of the length of extra time spent in the transportation system during a trip.

The measure can be averaged for streets, freeways, bus and carpool lanes, bus and rail transit, bicycle facilities and even sidewalks. All of these system elements have a freeflow travel rate and when crowded, the travel rate increases. (Theoretically, the index could even be used to measure Internet service conditions). An average corridor value can be developed using 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 hourly conditions and weighted by the number of travelers to estimate peak-period or daily index values.

One difficulty with the index can be summarized as “we do not have a rateometer in our cars, we have a speedometer.” Travel rate is unfamiliar to the general public. It has an inverse relationship to speed which can be confusing, but when the index is explained in simple terms—how much longer does it take to travel in the peak—the concept is not difficult to grasp. The public and businesses make mode, route and departure time decisions based on travel time concerns more than on a speed value; the travel rate is consistent with this decision-making approach.

The use of a continuous numerical scale addresses a shortcoming in the level-of-service technique that uses letter grades. Letter grades are easy to communicate, but the calculation procedures can produce some discontinuities when, for example, the next letter grade is only 10 vehicles from the volume being used for analysis. This “jump” in grade produces somewhat artificial differences between alternatives; these might be remedied with a numerical scale.

Percent of congested travel is primarily a system measure but can also help measure user experiences. A free-flow speed is used as the benchmark and any travel on a road section for a time period that is at less than the free-flow speed is determined to be congested.

This 2001 MMP report used a freeway speed of 60 mph as a congestion benchmark. Any 5-minute period with an average speed of less than 60 mph was recorded as congested and the travel in that time (measured in vehicle-miles traveled) included in the congestion measure. In practice, the measure may over-report the amount of congestion with this threshold. Unlike the other measures, the percentage of congested travel has an all-or-nothing characteristic. If the nighttime speed limit on the urban freeway system is 55 mph, a significant portion of travel could be categorized as congested, without a serious congestion problem being the cause.

Spot speed detectors are also more likely to record lower speeds than longer distance travel time measurements, due to their frequent location near entrance ramps and the much greater variation in speed over short sections than long sections. These considerations might suggest that a lower speed is more appropriate for the congestion threshold when using point-based sensors. This issue will be studied more in the 2002 MMP report.

Reliability Measures

All of the mobility performance measures reflect the *average level* of congestion and mobility. However, a number of empirical studies have demonstrated that travelers value not only the time it usually takes to complete a trip but also the reliability in travel times. For example, many commuters will plan their departure times based on an assumed travel time that is greater than the average to account for this unreliability.

From a performance monitoring standpoint, reliability must be considered because incident management and traveler information strategies target the atypical events that decrease reliability. This is important because it is usual for travel time savings to dominate the benefits assigned to major transportation improvement projects, and simply focusing on average conditions would miss a large share of the benefits that accrue from these operations strategies.

It seems appropriate to track several reliability performance measures. There is no single agreed-upon measure, and no customer/user market research has been performed. Even for these measures, it is not certain what level of reliability or variability (e.g., 85 percent, 90 percent, 95 percent) should be examined. This section identifies the measures that look the most promising or may provide relevant information for other analyses.

Percent variation, also known as the coefficient of variation, is the amount of variability in relation to the average travel rate. A traveler could multiply their average travel time by the percent variation, then add that product to their average trip time to get the time needed to be on-time about 85 percent of the time (one standard deviation above the mean). Higher values indicate less reliability. One advantage of expressing the variation in this way is that a percent value is distance and time neutral. The 2001 report used 5-minute data for non-holiday weekdays as the basic element of analysis to calculate standard deviation.

$$\text{Percent Variation} = \frac{\text{Standard Deviation}}{\text{Average Travel Time}} \times 100\% \qquad (4)$$

The **Buffer Index** is similar in concept to a measure developed for the HOWLATE program by Mitretek *(3)*. The Buffer Index expresses the amount of extra "buffer" time needed to be on-time 95 percent of the time (late one day per month). Indexing the measure provides a time and distance neutral measure, but the actual minute values could be used by an individual traveler for a particular trip length. The index is calculated for each road segment and a weighted average is calculated using vehicle-miles of travel as the weighting factor.

$$\begin{matrix}\text{Buffer}\\\text{Index}\end{matrix} = \begin{matrix}\text{Weighted}\\\text{Average of}\\\text{All Sections}\\\text{Using VMT}\end{matrix}\left[\frac{\begin{matrix}\text{95th Percentile Travel Rate}\\\text{(in minutes per mile)}\end{matrix} - \begin{matrix}\text{Average Travel Rate}\\\text{(in minutes per mile)}\end{matrix}}{\begin{matrix}\text{Average Travel Rate}\\\text{(in minutes per mile)}\end{matrix}} \times 100\%\right] \qquad (5)$$

The **Misery Index** seeks to measure the intensity of delay for only the worst trips. The average travel rate is subtracted from the upper 20 percent of travel rates to get the amount of time beyond the average for some amount of the slowest trips.

$$\begin{matrix}\text{Misery Rate}\\\text{(MR)}\end{matrix} = \begin{matrix}\text{Average of the travel}\\\text{rates for the longest}\\\text{20\% of the trips}\end{matrix} - \begin{matrix}\text{Average travel}\\\text{rates for all trips}\end{matrix} \qquad (6)$$

These three measures and corresponding graphics give a good idea of the type of information that can be provided to the public and agencies to evaluate the reliability component of system performance. It is also appropriate to consider some common variations of the descriptions of each of the above measures. Percentiles or confidence intervals are also useful. A mix of values and graphs are probably required in most applications—the values are good for quantifying the problem and analyzing solutions, the graphs and figures are good for illustrating the problem and the effect of potential solutions. It should be noted that all of these reliability measures are based on variations in travel rates and travel times.

Selection of Time Period

The time period over which the performance measures are computed must also be determined. Transportation engineers have traditionally used a peak hour, but congestion in major urban areas now occurs for multiple hours in both the morning and the afternoon. Use of a single peak hour misses the congestion that occurs during other times, prompting many areas to define a multi-hour *peak period*. Using a 3- to 4-hour peak period for all area sizes, however, may mask congestion for the smaller urban areas.

A consistent peak period length is necessary for any type of city-to-city comparison. Comparative studies between urbanized areas or studies of larger urban areas should probably use peak period analyses, rather than only a peak hour. Smaller areas can probably develop useful statistics with only peak hour analyses.

For national comparisons of reliability trends, a day-to-day comparison is appropriate. Calculating the amount of variation in travel conditions from day-to-day is a very useful measure of system reliability that matches key traveler and shipper decisions. For local purposes, where individual trip planning is also an issue, it will be useful to also include reliability in travel conditions over time within an hour or for the peak period.

The twin approach of both national and local focus is a strong point of the archived operations data analysis process, and strengthens the mobility and reliability information provided to a wide range of customers without a large incremental effort beyond a "basic approach." In other words, archived operations data is typically collected at a fine enough detail (both in time and space) to permit detailed local analyses (of, for example, a 3-mile freeway section). National analyses at a city or areawide level is simply accomplished by aggregating this detailed data.

5. The Results: What do the Measures Show….?

A number of trends and observations about the data and measures were discovered as a result of analyzing the 10-city database. This section details some of the general findings as well as specific summaries of the urban area data. Appendices A through J (posted on the study website at: http://mobility.tamu.edu/mmp) are reports for each of the 10 cities included in the year 2000 data analysis.

An important aspect of the study has been the relatively limited nature. There are only 10 cities in the database, but we received data about only freeways from these cities, only a portion of the freeways were instrumented, meaning that the information in the report covers only a portion of travel in each area. With all of these limitations, the reader should be very careful about extending the conclusions too far beyond those freeways that have operations sensor coverage.

Exhibit 5-1 illustrates one of the "only" aspects: the amount of system coverage. Six areas do not have coverage of half of the freeway system, and the portion of the system that is covered by operations sensors are not always the most congested roadway sections.

Exhibit 5-1. Instrumented Section Summary

City	Instrumented Corridors (centerline miles)	Urban Freeway System[1] (centerline miles)
Atlanta, GA	40 (13%)	306
Cincinnati, OH/KY	46 (26%)	174
Detroit, MI	117 (41%)	283
Hampton Roads, VA	19 (12%)	159
Houston, TX	225 (56%)	400
Los Angeles, CA	329 (51%)	641
Minneapolis-St. Paul, MN	192 (62%)	311
Phoenix, AZ	53 (38%)	138
San Antonio, TX	68 (32%)	211
Seattle, WA	99 (41%)	240

Note: [1]Total freeway centerline mileage obtained from Highway Performance Monitoring System (HPMS).

Measure Observations

The six measures presented in this report are a small subset of those that can be developed and that have been used to measure the performance of the transportation system or the user experience. The measures have been described as either mobility or reliability, but most non-technical readers and travelers see the two concepts as linked or even the same.

- The **mobility measures** illustrate different features of the system and travel. While there is some similarity in the story the measures tell, there are also some notable differences.

- The **delay per capita** measure will not be relevant until a substantial part of the system and travel can be instrumented. The values are not useful or comparable at this point, but the measure itself is a good one. The data might be supplemented with other data sources if the differences can be identified and adjusted.
- **Travel Time Index** has a much narrower range of values than was expected. The peak-period conditions that are included in the values in Exhibit 5-2 do not have the range of values between cities that are found in the Urban Mobility Study (UMS) Annual Report. There are a number of possible reasons:
    - ♦ The UMS Annual Report uses a relatively unsophisticated (when compared to the operations sensors) speed estimation process. There are a variety of potential inaccuracies.
    - ♦ The freeways included in the MMP are not a scientifically derived sample.
    - ♦ Ramp delay is not included in the MMP database.
    - ♦ The sensors that collect operations data are not always calibrated or functioning. Data are missing or inaccurate data may be present even after quality control.
    - ♦ The off-peak direction travel has grown and the high-speed operation that is typical of that direction is not properly accounted for in the UMS database.
    - ♦ The incident management activities and other operational improvements have a beneficial effect that is not captured in the UMS procedures. Most of the MMP cities have an incident management program as part of the corridor operations.

Exhibit 5-2. Mobility Statistic Summary

City	Travel Time Index	Delay per Capita (hours)	Percent Congested Travel
Atlanta, GA	1.14	0.8	25%
Cincinnati, OH/KY	1.25	2.0	61%
Detroit, MI	1.12	0.9	19%
Hampton Roads, VA	1.07	2.2	30%
Houston, TX	1.26	4.8	25%
Los Angeles, CA	1.33	4.4	41%
Minneapolis-St. Paul, MN	1.06	10.3	12%
Phoenix, AZ	1.11	2.6	49%
San Antonio, TX	1.08	4.0	35%
Seattle, WA	1.22	3.8	40%

Note: These values are for non-holiday weekday peak-period conditions.
Note: See website for more details: http://mobility.tamu.edu/mmp

- Exhibit 5-3 illustrates the three reliability performance measures considered in the study. One conclusion about the three measures is that the rankings of the 10 cities are relatively consistent. The same phenomenon is being measured with three slightly different methods and levels of unreliability. Because of their similarity, the decision was made to use only one of the measures—the Buffer Index—in the report because of the relative consistency of the analytical results.

Exhibit 5-3. Reliability Statistic Summary

City	Buffer Index	Misery Rate	Percent Variation
Atlanta, GA	27%	19%	22%
Cincinnati, OH/KY	37%	30%	31%
Detroit, MI	31%	21%	27%
Hampton Roads, VA	30%	16%	37%
Houston, TX	50%	28%	32%
Los Angeles, CA	46%	49%	26%
Minneapolis-St. Paul, MN	64%	33%	51%
Phoenix, AZ	43%	27%	33%
San Antonio, TX	32%	14%	25%
Seattle, WA	28%	25%	29%

Note: These values are for non-holiday weekday peak-period conditions.
Note: See website for more details: http://mobility.tamu.edu/mmp

Daily and Monthly Patterns

Some of the findings confirm the common knowledge about urban roadway systems. There are some others that point toward an expansion of the list of things that should concern transportation professionals. The issues might suggest new or expanded programs to address reliability issues and congestion in areas and during times that have not been a large concern in many areas.

There is also, however, some degree of skepticism associated with the statistics. The amount and intensity of congestion is not as significant or as widespread as many believe, and what other estimation processes and surveys indicate. Some of the differences are explainable, but the degree of difference is significant in some cases and will require some additional study. The differences could be related to:

- The data collection equipment and procedures
- The amount of roadway included
- Which sections of roadway are included
- New discoveries about the level of congestion on urban roadways.

Other main findings about the variation of congestion and mobility across the day and year include the following features.

- Using **average peak period values** to create the summary statistics provides a perspective more consistent with the user perspective than the average daily values. The average daily statistics indicate much lower congestion levels than the peak period.
- It seems clear that **off-peak direction travel** in most areas remains a) present—that is, there is an off-peak direction in most of the corridors studied, and b) reasonably good—that is, off-peak speeds are reasonably high. The growth in traffic volume in the off-peak

direction has led to higher speed trips being a larger portion of travel, thus lowering the average TTI value and lowering the apparent level of congestion.

- When the **off-peak direction reaches congested conditions**, the corridor average TTI rises significantly. Off-peak speeds that decline precipitously in the beginning of congested conditions (as described in the new Highway Capacity Manual) raise the peak period TTI by a significant amount.
- The **evening** peak period shows higher TTI values than the **morning** in eight of the 10 areas studied (Exhibit 5-4).
- The **midday period** of some facilities indicates **congestion**, and the Cincinnati data (Exhibit 5-4) indicate a potential systemwide problem, but the 60 mph speed chosen as the beginning of congestion may be part of the problem. Future analyses may use a lower speed congestion threshold to indicate the onset of congestion. This might eliminate the problem of slow drivers and slower nighttime vehicle operation from the measure statistics.
- The reliability measures (Exhibit 5-5 and Exhibit 5-6) follow the **same trend** as the mobility statistics – unreliability is higher in the evening peak than in the morning, and the midday period is not a significant problem in most cases.
- The **morning peak is also shorter** in most cities than the evening peak. A peak hour TTI that is much higher than the peak period TTI indicates a situation where conditions are reasonably good during the "shoulders" of the peak.
- The report statistics indicate that the chosen peak hours of 7 to 8 a.m. and 5 to 6 p.m. can produce relatively consistent statistics across all urban areas. Some local variations are probably desirable to illustrate local problems and trends. The peak hour TTI values are higher than the peak period TTIs.
- Exhibit 5-6 (for some cities) illustrates an **apparent additional peak** due to shift workers. The graph may also indicate a dip in congestion levels just before the morning peak, showing the effect of early commuters apparently trying to "beat the rush" by driving faster.
- The graph of Houston data similar to Exhibit 5-6 (Exhibit E-7 in the Appendix) is smoother than most other graphs due to the **travel time data collection devices** that collect section travel times, rather than the point data sources that estimate traffic speed at one spot on the road.

Exhibit 5-4. Daily Mobility Summary

City	Average Travel Time Index		
	Morning Peak Period	Midday Off-Peak	Evening Peak Period
Atlanta, GA	1.09	1.04	1.18
Cincinnati, OH/KY	1.20	1.16	1.29
Detroit, MI	1.11	1.04	1.13
Hampton Roads, VA	1.06	1.04	1.07
Houston, TX	1.22	1.07	1.30
Los Angeles, CA	1.34	1.07	1.32
Minneapolis-St. Paul, MN	1.08	1.04	1.04
Phoenix, AZ	1.08	1.02	1.13
San Antonio, TX	1.07	1.03	1.10
Seattle, WA	1.19	1.09	1.24

Note: See website for more details: http://mobility.tamu.edu/mmp

Exhibit 5-5. Daily Reliability Summary

City	Average Buffer Index (%)		
	Morning Peak Period	Midday Off-Peak	Evening Peak Period
Atlanta, GA	19	14	31
Cincinnati, OH/KY	29	20	46
Detroit, MI	30	10	32
Hampton Roads, VA	31	21	40
Houston, TX	71	28	79
Los Angeles, CA	45	46	46
Minneapolis-St. Paul, MN	36	27	45
Phoenix, AZ	51	17	68
San Antonio, TX	26	10	52
Seattle, WA	26	22	30

Note: See website for more details: http://mobility.tamu.edu/mmp

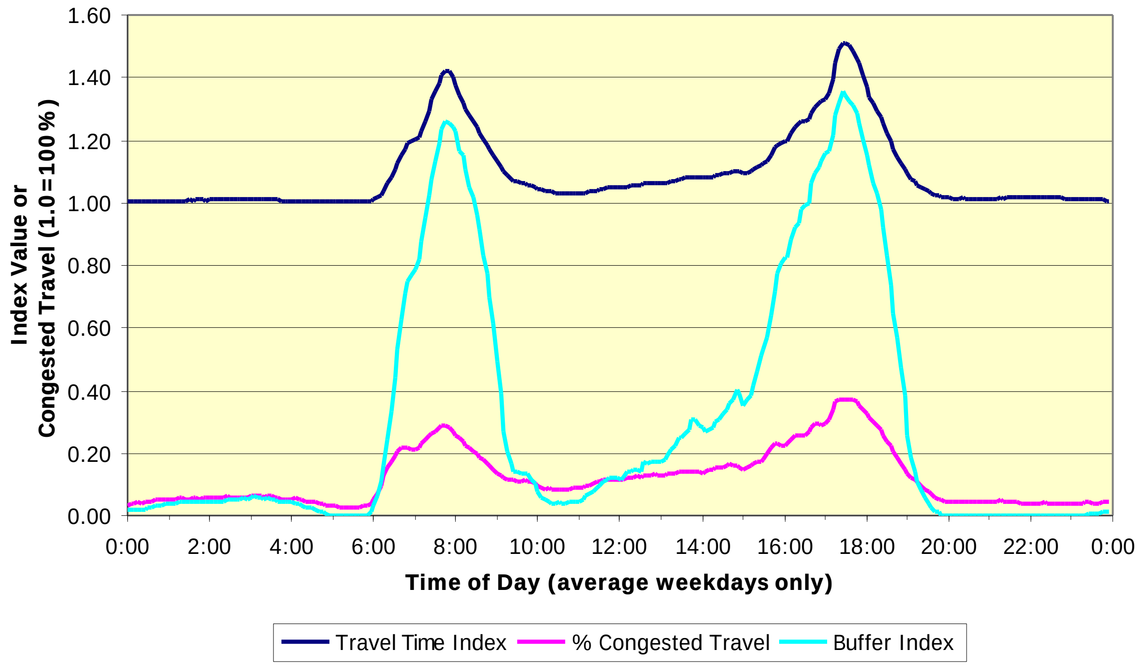


Exhibit 5-6. Mobility and Reliability Measures by Time of an Average Day, Houston (Example)

Note: See website for more details: http://mobility.tamu.edu/mmp

- **Midday delay** (measured in hours) is higher than the morning delay in four of the cities and is a significant element of delay in two other cities. Even cities that are relatively congested in the peak period have a significant amount of midday delay. The intensity is not as great due to the longer period – seven hours rather than three hours.
- A portion of the delay is due to **speeds between 50 mph and 60 mph** during the off-peak, particularly in the overnight period.
- **Overnight delay** is close to or more than 20 percent of daily delay in four areas and more than 10 percent in all but Houston. This shows the impact of the link travel time data collection devices in Houston as opposed to the point data collection in the other nine cities. It is more likely that there are slow speeds for a short section of road near a data collection device, than over a two or three mile section.

Exhibit 5-7. Daily Delay Summary

City	Time of Day Delay (Percent)				
	Early Morning	AM Peak	Midday	PM Peak	Late Evening
Atlanta, GA	10	24	11	47	8
Cincinnati, OH/KY	9	27	20	34	10
Detroit, MI	15	28	12	33	12
Hampton Roads, VA	4	20	37	27	12
Houston, TX	0	30	22	47	1
Los Angeles, CA	8	27	31	21	13
Minneapolis-St. Paul, MN	4	20	37	27	12
Phoenix, AZ	12	19	29	28	12
San Antonio, TX	4	23	28	34	11
Seattle, WA	9	33	15	38	5

Note: See website for more details: http://mobility.tamu.edu/mmp

- Exhibit 5-8 is an effective method of illustrating the share of delay over time of day.
- Exhibit 5-9 indicates **weekend delay** may be equal to the delay for one weekday in about half of the cities. The data collection device differences may be part of this, but the statistics are not as striking. Although sweeping conclusions should be avoided, the weekend delay problem may be a subject for study, particularly in certain corridors.
- **Monday delay** is typically less than other weekdays.
- **Thursday or Friday delay** is typically highest.
- Exhibit 5-10 is an effective picture of delay distribution during the week.

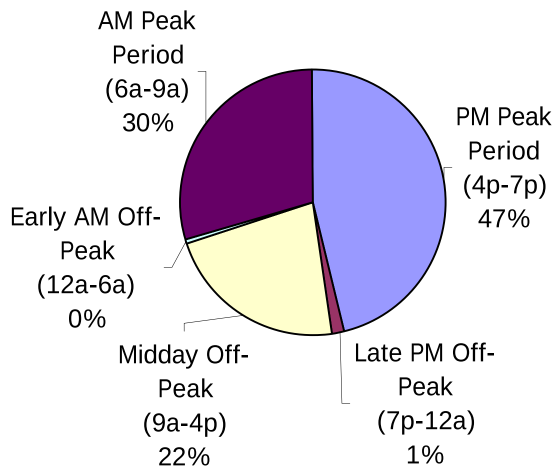


Exhibit 5-8. Delay by Time of Day (Example)

Note: See website for more details: http://mobility.tamu.edu/mmp

Exhibit 5-9. Day of Week Summary

City	Day of Week Delay (Percent)						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Atlanta, GA	14	14	16	20	22	6	8
Cincinnati, OH/KY	15	17	19	19	19	5	6
Detroit, MI	15	16	17	18	15	10	9
Hampton Roads, VA	16	18	16	17	16	9	8
Houston, TX	15	18	20	20	21	4	2
Los Angeles, CA	14	16	20	17	20	9	4
Minneapolis-St. Paul, MN	14	18	22	25	15	3	3
Phoenix, AZ	14	17	16	16	16	11	10
San Antonio, TX	15	16	16	18	19	8	8
Seattle, WA	17	18	17	18	20	5	5

Note: See website for more details: http://mobility.tamu.edu/mmp

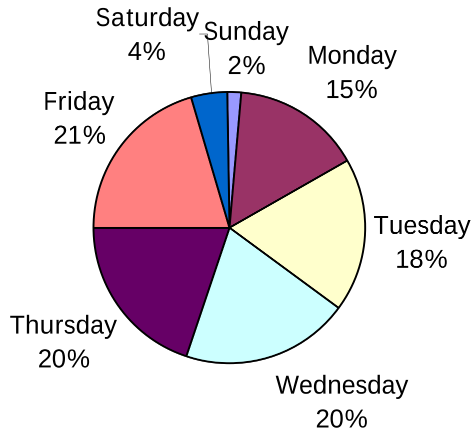


Exhibit 5-10. Delay by Day of Week (Example)

Note: See website for more details: http://mobility.tamu.edu/mmp

- Exhibit 5-11 presents **two congestion and one reliability** measure in a single graph. The TTI has a minimum of 1.0, while the other two measures range from 0 to 1 or greater. Daily relationships between mobility and reliability in a city can be investigated with this Exhibit.

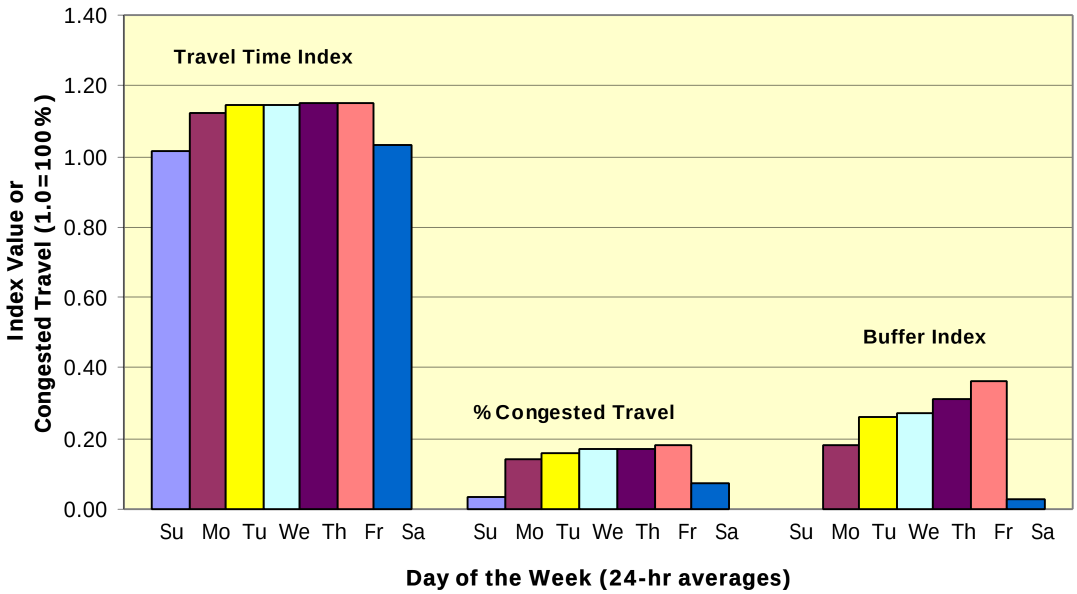


Exhibit 5-11. Mobility and Reliability Measures by Day of the Week (Example)

Note: See website for more details: http://mobility.tamu.edu/mmp

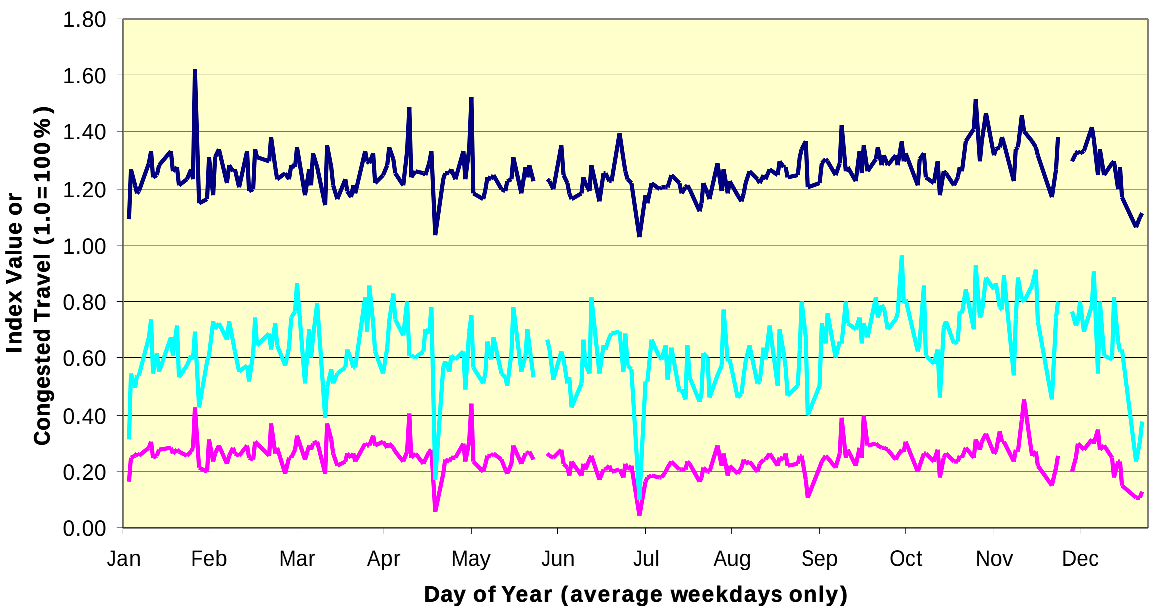


Exhibit 5-12. Mobility and Reliability Measures by Day of the Year (Example)

Note: See website for more details: http://mobility.tamu.edu/mmp

- Exhibit 5-12 can be used to illustrate the **daily variation** in the measures. It is particularly useful in identifying seasonal variations and "spike" days of unusually bad or good conditions. They identify special events, weather problems, and other irregular occurrences – some events can be planned for and others can only be dealt with.

Corridor Observations

Some of the instrumented corridors illustrate issues that have been measured by travel time data collection in the past, but rarely as completely as is possible with full-time data collection abilities.

- Exhibit 5-13 provides a list of the highest values from each city for the mobility and reliability measures. There is a similarity in the rankings for each measure—**congested road sections are also unreliable road sections**.
- Most of the top 10 lists include **peak periods**, but weather days, delay or unreliability from significant accidents and other events also appear.
- Exhibit 5-14 is a method of highlighting key delay locations.

Exhibit 5-13. Most Congested and Least Reliable Travel Periods for 2000

City	#1 Most Congested		#1 Least Reliable	
	Travel Time Index	Day and Time Period	Buffer Index	Day and Time Period
Atlanta GA	2.97	March 31, PM Peak	222	Nov. 20, PM Peak
Cincinnati OH/KY	3.25	Aug. 14, AM Peak	547	April 18, AM Peak
Detroit MI	5.66	Dec. 11, PM Peak	752	Dec. 11, PM Peak
Hampton Roads VA	4.35	Oct. 23, AM Peak	986	Jan. 26, PM Peak
Houston TX	6.26	June 21, PM Peak	709	Oct. 12, Late PM Off Peak
Los Angeles CA	4.28	Oct. 4, AM Peak	226	Oct. 27, Midday Off Peak
Minneapolis-St. Paul MN	8.85	Dec. 18, PM Peak	926	Dec. 12, AM Peak
Phoenix AZ	3.06	Aug. 28, PM Peak	592	Aug. 28, Midday Off Peak
San Antonio TX	2.69	Feb. 1, PM Peak	419	Aug. 4, Midday Off Peak
Seattle WA	3.51	Aug. 3, PM Peak	230	Jan. 7, PM Peak

Note: See website for more details: http://mobility.tamu.edu/mmp

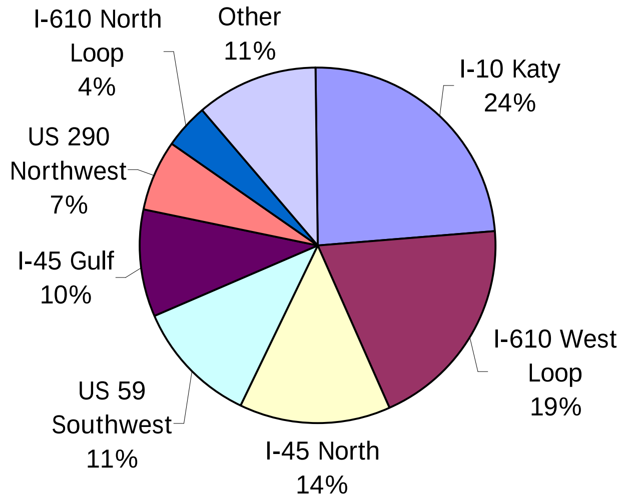


Exhibit 5-14. Delay by Roadway (Example)

Note: See website for more details: http://mobility.tamu.edu/mmp

HOV lanes that are instrumented separately (some are included in the adjacent freeway data) show that they are much more reliable and have very low (i.e., desirable) travel time index values.

- Toll highways are more reliable and have lower travel time index values.
- A few major street or expressway sections in Minneapolis that are instrumented show very reliable performance. The speeds are slower, but incidents and/or weather affect the performance less.
- If many miles of roadway are instrumented in a city, the presentation of the data becomes cumbersome. There can be many sections of roadway with many corresponding figures and charts. The information requires organization and highlights to point the readers to important elements. However, local analysts will be most interested in performance measures at the facility level or lower. Local elected officials and media may show more interest in an areawide measure.
- Most directional roadways in the study have a single peak. There are "double-peak" corridors, but many of the congested sections show very short periods of off-peak direction congestion. If these data are true, it could be the cause of overestimates of delay in procedures that assume an equal directional distribution.
- Exhibit 5-15 compares the percentage delay values for each corridor to the share of system capacity (measured in percent of lane-miles) and system travel (measured in percent of vehicle-miles traveled) in each city. (These values are only for the instrumented sections of freeway). The sections most in need of attention are those with percent delay values much higher than percent roadway or travel.

Exhibit 5-15. Roadway, Travel and Delay

City	Corridor	Instrumented Lane-Miles		Annual VMT		% of Delay
		Lane-Miles[1]	% of City	(1000)	% of City	
Atlanta	I-75A	64	19%	722	22%	13
	I-75B	42	12%	575	17%	40*
	I-75C	73	21%	797	24%	16
	I-85A	26	8%	217	7%	2
	I-85B	137	40%	997	30%	28
	Total	342	100%	3,308	100%	100
Cincinnati	KY I-275	70	21%	334	19%	5
	KY I-71/I-75	88	27%	225	13%	24
	OH I-275	59	18%	276	16%	5
	OH I-75	111	34%	909	52%	66*
	Total	327	100%	1,744	100%	100
Detroit	I-696A	127	15%	935	17%	14
	I-696B	74	9%	444	8%	5
	I-75	138	17%	936	17%	24
	I-94A	130	16%	663	12%	4
	I-94B	78	9%	364	7%	2
	I-96A	43	5%	570	10%	29*
	I-96C	147	18%	894	16%	4
	MI 10	13	2%	154	3%	1
	MI 39	82	10%	607	11%	17
	Total	833	100%	5,567	100%	100
Hampton Roads	I-264	64	37%	1,388	33%	33
	I-564	16	9%	655	16%	6
	I-64	92	54%	2,141	51%	61*
	Total	171	100%	4,184	100%	100
Houston	Hardy Toll Road	106	6%	355	3%	0
	I-10 East	124	7%	764	6%	3
	I-10 Katy	156	8%	1,348	11%	24*
	I-45 Gulf	197	11%	1,480	12%	10
	I-45 North	206	11%	1,655	13%	14
	I-610 East Loop	102	6%	454	4%	1
	I-610 North Loop	90	5%	521	4%	4
	I-610 South Loop	93	5%	469	4%	1
	I-610 West Loop	90	5%	751	6%	19*
	N. Sam Houston Parkway	53	3%	432	3%	1
	Sam Houston Tollway	82	4%	706	6%	1
	SH 288 South	27	1%	158	1%	0
	US 290 Northwest	133	7%	858	7%	7
	US 59 Eastex	156	8%	593	5%	2
	US 59 Southwest	179	10%	1,522	12%	11
	W. Sam Houston Parkway	58	3%	474	4%	1
	Total	1852	100%	12,539	100%	100

Exhibit 5-15. Continued

City	Corridor		Instrumented Lane-Miles		Annual VMT		
			Lane-Miles[1]	% of City	(1000)	% of City	% of Delay
Los Angeles	CA 60		48	15%	13,074	12%	16
	I-10		36	11%	10,563	10%	15
	I-105		16	5%	4,464	4%	5
	I-110		13	4%	2,931	3%	6
	I-210		48	15%	22,721	21%	10
	I-5		78	24%	24,589	23%	22
	I-605		52	16%	16,218	15%	10
		Total	329		107,546		
Minneapolis-St. Paul	I-35E		175	18%	25,402	27%	14
	I-35W		142	14%	6,245	7%	18
	I-394		55	6%	4,086	4%	5
	I-494		144	15%	5,358	6%	21*
	I-694		31	3%	25,304	27%	2
	I-94		176	18%	7,088	8%	21
	MN 36		31	3%	1,811	2%	2
	MN 5		10	1%	634	1%	0
	MN 55		3	0%	10	0%	0
	MN 62		51	5%	502	1%	4
	MN 65		1	0%	0	0%	0
	MN 77		27	3%	6,392	7%	2
	TH 110		1	0%	8	0%	0
	TH 13		2	0%	6	0%	0
	US 100		55	6%	2,852	3%	5
	US 12		14	1%	1,125	1%	0
	US 169		67	7%	5,569	6%	6
	US 212		10	1%	1,951	2%	0
		Total	996	100%	94,342	100%	100
Phoenix	I-10		180	43%	4,588	31%	67*
	I-17		104	25%	1,142	8%	13
	L202		27	6%	2,581	18%	7
	SR143		17	4%	175	1%	1
	SR51		90	22%	6,127	42%	12
		Total	417	100%	14,613	100%	100
San Antonio	I-10		156	35%	8,684	57%	43
	I-35		111	25%	960	6%	21*
	I-37		34	8%	1,235	8%	4
	US 90		13	3%	1,321	9%	1
	US 281		26	6%	251	2%	8
	I-410		92	21%	2,060	14%	21
	Loop 1604		10	2%	711	5%	3
		Total	444	100%	15,221	100%	100

Exhibit 5-15. Continued

City	Corridor	Instrumented Lane-Miles: Lane-Miles[1]	Instrumented Lane-Miles: % of City	Annual VMT: (1000)	Annual VMT: % of City	% of Delay
Seattle	I-405A	57	8%	429	9%	11
	I-405B	147	20%	935	19%	20
	I-5A	112	15%	819	16%	13
	I-5B	37	5%	277	6%	7
	I-5C	179	24%	1,283	26%	24
	I-90A	48	6%	275	5%	5
	I-90B	55	7%	250	5%	2
	SR-167	58	8%	380	8%	6
	SR-520A	19	2%	167	3%	7*
	SR-520B	33	4%	200	4%	5*
	Total	745	100%	5,015	100%	100

[1]Directional miles shown; Lane-mile information not available in Los Angeles.
*Sections most in need of attention.
Note: See website for more details: http://mobility.tamu.edu/mmp

6. The Future: Additional Opportunities

The first year of the Mobility Monitoring Program has shown the great potential of using archived operations data for performance monitoring. As the Program moves forward, a number of opportunities present themselves for improving and expanding the concepts demonstrated in the first year.

Validation of Travel Times from Multiple Sources

The data from the 10 cities participating in the first year were generated primarily from roadway surveillance equipment that collects volumes and speeds at spot locations. Several issues associated with this form of data exist, and should be examined.

- A simple technique was used to extrapolate spot speeds to link travel times. The accuracy of these estimated travel times (as compared to probe vehicle travel times) is unknown.
- A variety of technologies are being used to collect spot speeds including single- and double-inductance loops, radar, passive acoustic, and video image processing. Tests by Minnesota DOT have shown that the technologies can produce comparable results, although testing continues and should be monitored. A specific concern of the Project Team is that speeds estimated from single inductance loops are significantly different from those that measure speeds directly. As agencies adopt the next generation of technologies this issue may take care of itself, but in the short-term it remains a concern.
- Because the first year of the Program relied solely on freeway detection, the results are viewed from a facility perspective. Of at least equal importance is the user perspective, i.e., how trips taken by travelers (from origin to destination) are affected by congestion. Areawide estimates of mobility may differ if measures are built up from trips rather than from facilities. Although both views are important – facility performance for operators and trip performance for travelers – it is important to know the relationship between the two approaches of measurement.
- Comparison of the empirical results from the first year of the Program with other analytic methods will be enlightening. The state-of-the-practice in performance monitoring is currently dominated by analytic methods such as the *Highway Capacity Manual* and the Highway Performance Monitoring System. How these methods compare to the results produced by this study – at both the corridor and areawide levels – is not known and should be tested.

Expansion of the Program to Include Signalized Arterials

A significant portion of urban travel occurs on signalized highways and should be included in mobility estimates. However, estimating travel times on arterials using existing technologies is problematic. Spot speeds are usually taken at mid-block locations but most of the delay occurs at the intersections (mid-block speeds are likely to be free-flow unless queues are excessive). Probe-based systems are clearly superior but are not very common. Some combination of mid-block detection coupled with computer simulation could prove useful. In such an approach, the mid-block volumes are used as demand inputs to simulating the performance of a signal for very short time intervals (e.g., 1- to 5-minutes). This approach also requires details on signal operation: phasing and turning movements. If these data were available at the same time, results would be more accurate than if defaults were used. This is particularly the case where advanced signal control strategies are used to adjust phasing in real-time.

More Sophisticated Quality Control Procedures

Common practices for examining the quality of archived operations data are still relatively unsophisticated and much work remains to be done. On-going work at Virginia's Smart Travel Laboratory and the University of Washington should be investigated for their applicability nationwide. The advanced data quality checks that should be investigated include:

- Sequential Data Checks – will compare values in consecutive time periods for consistency (e.g., speeds cannot go from 60 mph to 20 mph and back to 60 mph in consecutive 5-minute time periods.
- Corridor Data Checks – will examine the relationship between data along a corridor (e.g., volume into an area should approximately equal volume out).
- Historical Data Checks – will examine the changes from one year to the next for reasonableness (e.g., high increases in volume or drastic changes in speeds).

Data quality checks are only the first step in the QC process – once suspicious or erroneous data are detected, an action must be taken. Possible actions include simply flagging or replacing the data. Methods for replacing QC-failed data, as well as for imputing missing data, offer the chance to improve data completeness. Such methods would be based on "good" data from surrounding locations for the same time period as well as using historical data.

Analyses Tailored to Local Areas

The field visits with state and local personnel revealed a strong interest in performance monitoring. However, it was apparent that the local view of performance monitoring has a different focus than that of FHWA. Specifically, state and local personnel are more concerned with the geographic detail of mobility. Planners and operators both expressed this need, although their interests are at slightly different time and spatial scales: operators from the perspective of "what happened at a specific bottleneck yesterday and what can we expect today" and planners from the perspective of "how have travel trends in extended corridors changed over long periods of time". In spite of their interest, however, the ability to perform these analyses on very large datasets is not common.

Local universities often assist, but their focus tends to be on research. A clear exception is in Seattle where the University of Washington produces an annual regional mobility report. However, even their local use of the data for other purposes is not widespread.

If local agencies are to take full advantage of archived operations data, additional resources will be needed for maintaining and analyzing archived operations data. The website contains information on the individual city reports developed for this study. (For more details see: http://mobility.tamu.edu/mmp).

Congestion Causes

The measures developed so far provide an overall picture of mobility. However, to be more useful for implementing operations strategies, the *causes of congestion* should be tracked. In other words, what factors ("events") have contributed to overall mobility and what are their magnitude; factors include incidents, weather, work zones, changes in traffic demand and recurring bottlenecks. Ideally, the share of total congestion attributable to these sources is desirable: this allows strategies to be targeted at the root causes. 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).

The first step in this process is to construct a comprehensive database that contains not only roadway surveillance data (e.g., the data from the 10 cities used in the first year of the Program) but data on the external factors as well. The experience of the Project Team has been that the archiving of external factors, such as incidents, is sporadic and even less standardized than roadway surveillance data. Once data have been archived, research is needed to link the surveillance data with the external factors. For example, delays in a corridor can be attributed to incidents on one day, weather on another, and high demand on another.

Continue to Experiment with Measures

The measures used in this report are useful and many have been presented to general audiences through other reports. They are not the only measures and while local agencies will experiment with their own measures, the national study should also investigate other measures. The range of uses, from real-time information to long-term planning will mean that a variety of measures will always be appropriate.

Encourage the Development of Standardized Procedures for Data Archiving

Although it is apparent that many TMCs are now archiving data, the Project Team found considerable differences in how the archiving is performed. Although accounting for the differences can be done, it takes considerable effort to do so. As the number of participating cities grows, this effort will become nontrivial. Beyond the ease of analysis, a more important consideration is that standardized procedures for collecting and (especially) managing the data will allow more meaningful comparisons across cities. Standards for archived data will also promote use of the data among local agencies and the private sector, such as in use for ATIS applications (e.g., historical patterns for short-term travel time prediction) and software vendors (e.g., TMC system integrators). Finally, if local processing and reporting of the data is the long-term goal of the Mobility Monitoring Program, then standards are necessary to ensure consistent results.

Specifically, the areas where standardization would improve analysis and use of the data by local agencies are:

- **File Formats.** Individual file extraction and input procedures for each city must now be made. A common file structure and file storage/compression formats would greatly promote analysis.
- **Aggregation Procedures.** Data are currently submitted at various levels of time and spatial aggregation; a common aggregation definition would also ease the analysis burden. Also, internal procedures at the TMCs differ in how aggregation is performed. Treatment of missing values and the computation of average speeds are two such procedures that if standardized would allow more direct comparisons to be made.
- **Quality Control.** The degree of quality control varies substantially across the 10 cities. Application of different thresholds by the TMCs result in slightly inconsistent data. Standardized QC procedures would improve this situation and also would help TMCs get more closely acquainted with the details of their data.
- **Metadata/Meta-Attributes.** Documentation on how the data were collected and processed would allow analysts to determine the usefulness and accuracy of the data to a higher degree than now possible. One example would be documenting the number of observations that comprise an aggregated record; some of the systems supplying data for this study provide this function, but others do not.

Long-Term Structure of the Mobility Monitoring Program

The long-term success of the Mobility Monitoring Program hinges on strong local involvement. The current process is based on the Project Team obtaining and processing the data for each area. This structure is necessary in the beginning to identify and resolve the many technical and institutional issues that have been uncovered. However, as the number of participating cities grows in future years, the amount of data processing needed to support the program will be substantial and has large cost implications. Further, local use of the data should be encouraged for quality purposes—problems can be quickly identified and fixed if local areas are actively engaged in applying the data to local applications. Therefore, the future structure of the Program should evolve toward more local control, with the Federal reports being just one of many uses of the data by local agencies. Standards and technical assistance are needed to support the transition to local control.

References

1. Ishimaru, John, *CDR User's Guide*, Washington State Transportation Center, March 1998.

2. 2001 Urban Mobility Report, Texas Transportation Institute, May 2001.

3. Wunderlich, K.E., Hardy, M.H., Larkin, J.J. and Shah, V.P. *On-Time Reliability Impacts of Advanced Traveler Information Services (ATIS): Washington, DC Case Study*. Mitretek Systems, January 2001.

Appendix A—Atlanta, GA

2000 Regional Mobility and Reliability Data

A Supplement to:

Monitoring Urban Roadways: Using Archived Operations Data for Reliability and Mobility Measurement by Texas Transportation Institute and Cambridge Systematics, Inc., May 2001.

Atlanta, GA Findings

- A four-mile section of I-75 near and north of downtown has half of the estimated delay.
- ¾of delay occurs in either the morning or evening peak periods.
- The weekend days have as much delay as a typical weekday.
- Unreliability and congestion peak at the same time.
- Midday congestion is low and reliability high.
- The freeway sections outside of downtown do not have a high congestion level.
- Reliability levels differ significantly for the peak periods—the morning has much more consistent travel times than the evening.

Atlanta, GA Data Source

- Atlanta's data were supplied from the NaviGAtor system, operated by the Georgia Department of Transportation. Approximately 40 miles of the more than 300-mile freeway system is included in the archived data system.
- Current surveillance coverage is on I-75 and I-85 inside of Atlanta's Beltway (I-285). NaviGAtor is now expanding its coverage to the Beltway and to portions of I-75 north of the Beltway. The covered system includes the section of highway with the highest daily traffic volumes anywhere in the U.S: more than 410,000 vehicles per day (I-75 immediately south of the I-85 interchange).
- The data was collected using video image processing. Direct speed estimates are obtained and reported by lane at 15-minute intervals. A radar-based speed data collection system is noted in Exhibit A-2. Unfortunately, data from this system is not included in the data archive.
- 89% of both the volume and speed data in the original data archive passed the initial quality control tests.
- The original data records included volume and speed for 81% of the time periods in 2000.
- After removing data that failed the quality control checks and identifying missing data, 72% of the possible speed and volume records were found to be usable for further analysis.
- Although not archived in 2000, the NaviGAtor system will begin to collect and store vehicle length information from the video image processing equipment in the near future; this will provide basic information on truck travel, a persistent data gap for heavily traveled urban highways where traditional automatic vehicle classifiers cannot be used (due to varying vehicle speeds).

Major Study Findings (Why you should read the Final Report)

- It is only 36 pages.
- Local data archiving occurs in some areas but easy accessibility and use of that data is much less widespread. Database management and analytical methods can be somewhat complex, and limited local resources and guidance have also hindered widespread development of easy-to-use data archives. Each area has essentially pursued their own development schedule and scope with funding from local sources. The report, and the associated best practices guide can assist agencies in the data archiving process.
- The mobility and reliability measures used in the report can most efficiently be used for local area trend analysis and analysis of important subjects at the national level. The data are less useful for city-to-city comparisons because of the incomplete ITS coverage and inconsistencies between cities. The report summarizes the measures used in the study and demonstrates how they can be prepared and interpreted.

Exhibit A-1. Trends in Mobility and Reliability Indicators

Indicator	2000	1999	Change
MOBILITY			
Travel Time Index	1.14		
Delay per Capita (hours)	0.8		
Percent Congested Travel	25%		
RELIABILITY			
Buffer Index	27%		
Misery Rate	19%		
Percent Variation	22%		

Notes: [1]These performance measures represent the portion (39.6 miles) of the total freeway system (306 miles) that contains ITS traffic monitoring sensors.

[2]All statistics reported in this exhibit are peak period averages for all weekdays in the year indicated (no holidays included).

[3]This exhibit will be used to illustrate annual trends once we have more than one year of data.

Data analysis by Texas Transportation Institute and Cambridge Systematics, Inc.
Data provided by Georgia DOT.

Travel Time Index—A ratio of peak travel rate to a free-flow travel rate. A TTI of 1.3 indicates a 20-minute off-peak trip would take 26 minutes in the peak.

Delay per Capita—Estimate of the annual delay (in hours) per person in the urban area. Until a larger percentage of the system is instrumented, this value will be artificially low.

Percent Congested Travel—The percentage of vehicle-miles of travel that occur below 60 mph.

Buffer Index—The percentage of time above the average necessary to allow travelers to arrive on time for 95% of trips. The difference between the 95th and average travel rate divided by the average travel rate.

Misery Rate—The length of delay for the most congested 20% of the trips. The average travel rate is subtracted from the average rate for the slowest 20% of the trips. The Misery Rate is a percentage of extra time needed for the worst 20% of the trips.

Percent Variation—The amount of extra time needed to be on-time for 85% of the trips. Calculated as the standard deviation divided by the average travel rate.

An exhibit will be inserted here to illustrate annual trends once we have more than 1 year of data.

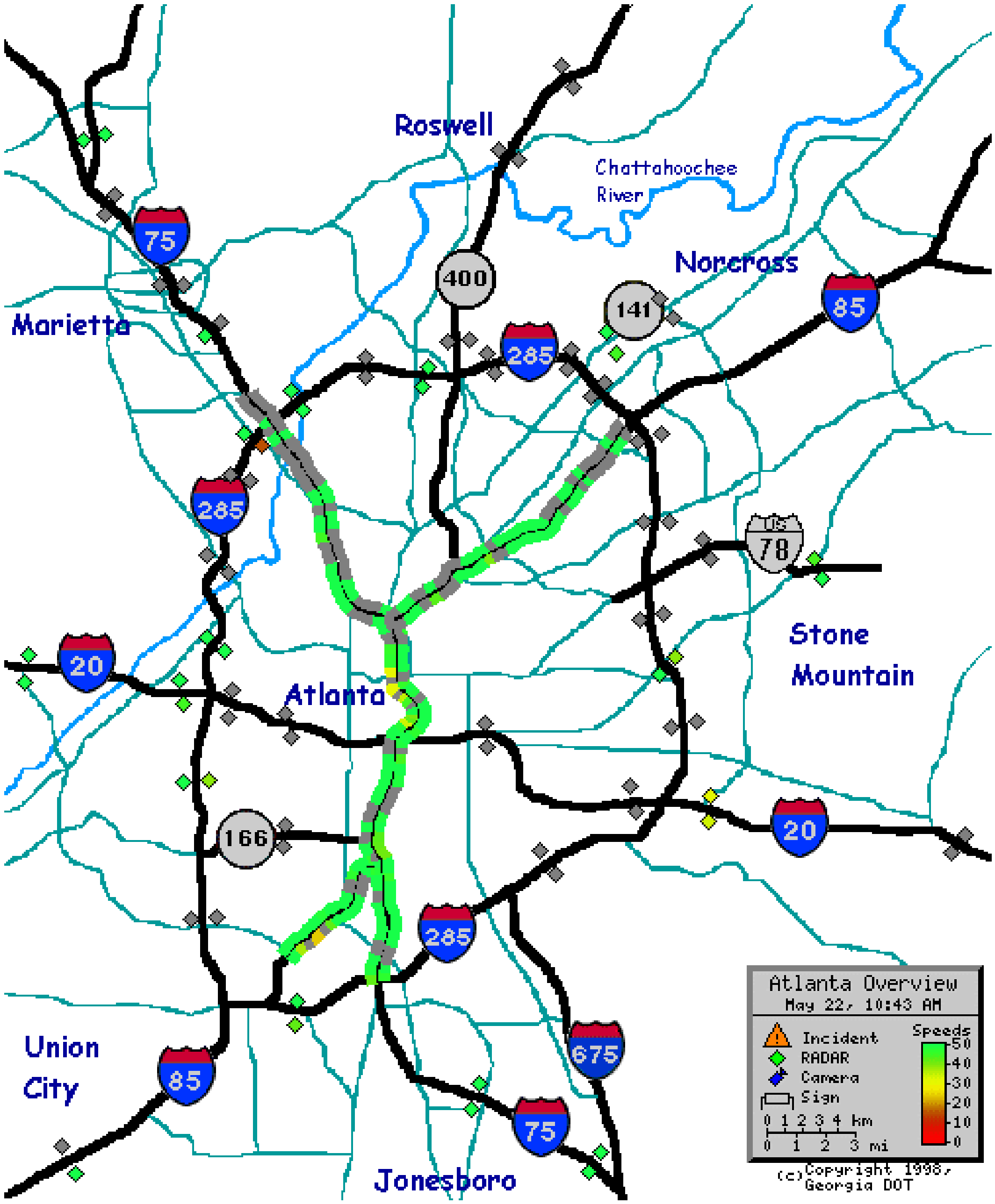


Exhibit A-2. Atlanta, Georgia Regional Area
(Source: Georgia DOT's NaviGAtor, http://www.georgia-navigator.com/traffic)

Routes included in performance measure estimates:

I-75 (NB 21.40 mi, SB 21.40 mi)
I-85 (NB 18.159 mi, SB 18.159 mi)

Where and When Delay Occurs

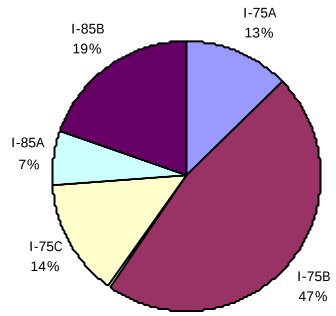


Exhibit A-3. Delay by Roadway

- Almost half of delay happens on I-75B.
- I-75A&B and I-85A&B share the remainder of the delay.

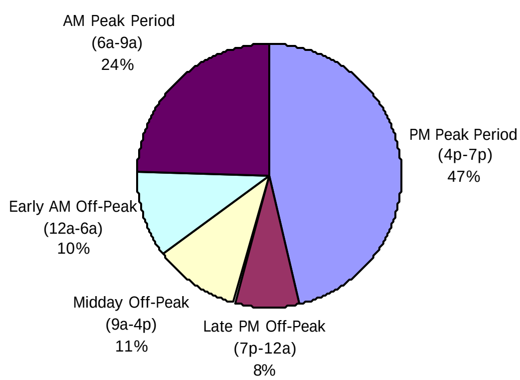


Exhibit A-4. Delay by Time of Day

- ¾ of delay occurs in one of the peak periods.
- Almost half of delay is in the evening peak.
- Relatively little delay occurs in the midday.

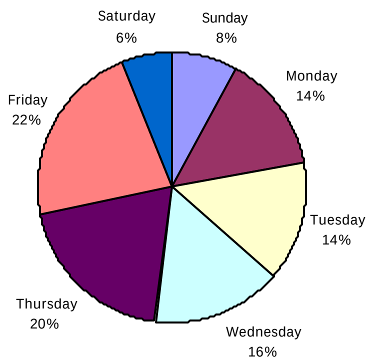
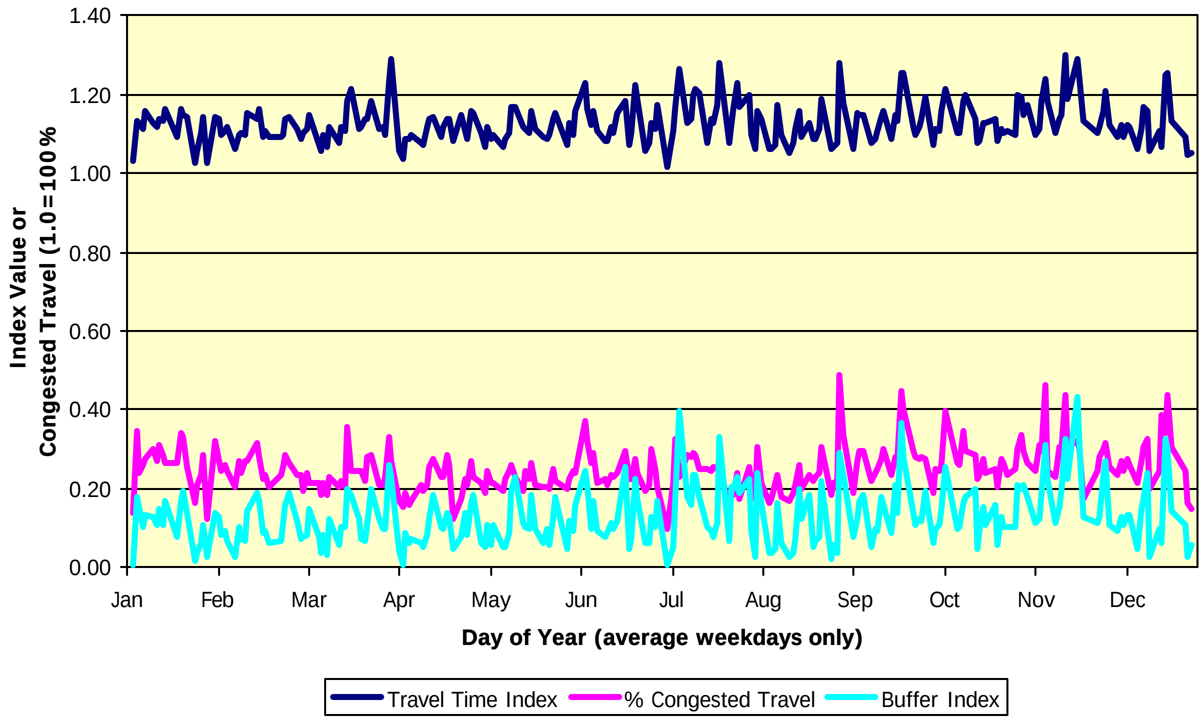


Exhibit A-5. Delay by Day of Week

- The weekend days combined have as much delay as a typical weekday.
- Delay grows each weekday through the week; Friday delay is significantly greater than Monday.



Note: Trend lines will be added to this graph when data from a sufficient time has been collected. Until multiple years of data are analyzed, the apparent trend may only be a seasonal variation in travel conditions.

Exhibit A-6. Mobility and Reliability Measures by Day of the Year

- Congestion and reliability problems follow approximately the same pattern.
- There is very little seasonal variation in congestion and reliability.

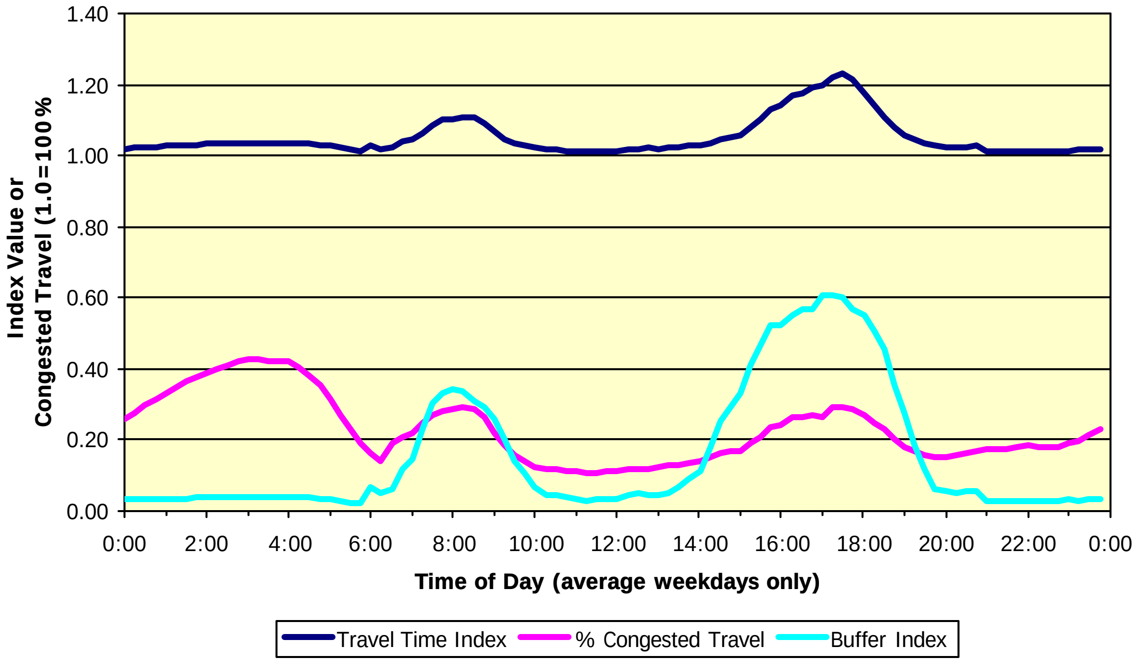


Exhibit A-7. Mobility and Reliability Measures by Time of an Average Day

- Congestion and unreliability follow the same pattern through the day.
- The apparent congestion between 2 and 4 a.m. is probably caused by speeds just below 60 mph. The TTI in this time remains very low.
- Congested travel drops as the morning peak nears, indicating drivers attempting to "beat the rush hour" and the effect of more sunlight after 6 p.m.
- Off-peak congestion is relatively low and reliability high.
- Evening peak conditions are worse and remain that way for longer than the morning peak.

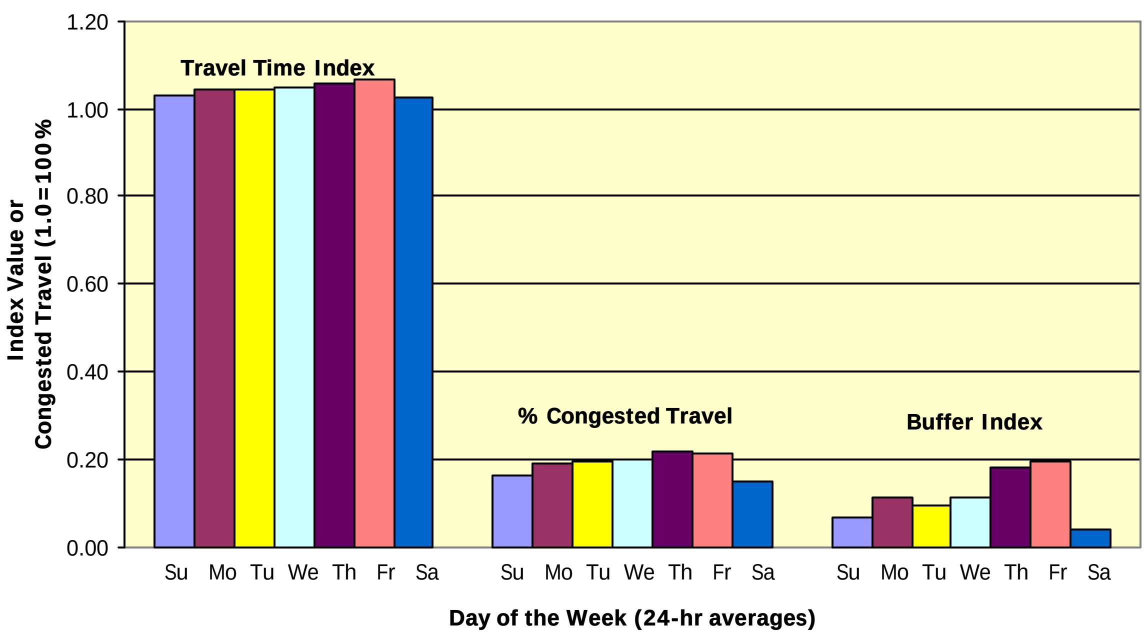


Exhibit A-8. Mobility and Reliability Measures by Day of an Average Week

- Thursday and Friday are the least reliable days, as well as the most congested.

2000 MOBILITY AND RELIABILITY REPORT—
BY DIRECTIONAL SECTION, ATLANTA, GEORGIA

Exhibit A-9. Top Ten List—Most Congested Peak Periods

Rank	Directional Section	Date	Time Period	Travel Time Index
1	I-75C NB	March 31, 2000	PM Peak Period	2.97
2	I-75B SB	April 24, 2000	PM Peak Period	2.70
3	I-75C NB	November 20, 2000	PM Peak Period	2.63
4	I-75B SB	November 21, 2000	PM Peak Period	2.45
5	I-75B SB	June 23, 2000	PM Peak Period	2.40
6	I-75C NB	March 17, 2000	PM Peak Period	2.38
7	I-75B SB	November 16, 2000	PM Peak Period	2.34
8	I-75B SB	August 10, 2000	AM Peak Period	2.33
9	I-75B NB	March 30, 2000	PM Peak Period	2.32
10	I-75B NB	November 16, 2000	PM Peak Period	2.31

Exhibit A-10. Top Ten List—Least Reliable Peak Periods

Rank	Directional Section	Date	Time Period	Buffer Index
1	I-75C NB	November 20, 2000	PM Peak Period	222%
2	I-75B NB	November 10, 2000	PM Peak Period	220%
3	I-75B NB	November 9, 2000	PM Peak Period	217%
4	I-75B NB	November 2, 2000	PM Peak Period	210%
5	I-75B NB	November 3, 2000	PM Peak Period	208%
6	I-75C NB	March 31, 2000	PM Peak Period	202%
7	I-75B NB	March 30, 2000	PM Peak Period	197%
8	I-75B NB	November 8, 2000	PM Peak Period	171%
9	I-75B NB	May 11, 2000	PM Peak Period	155%
10	I-75C NB	March 17, 2000	PM Peak Period	154%

- Evening peaks dominate both lists.
- November was the most congested and least reliable month.
- I-75B SB, a central city corridor, had several significantly bad peak periods.
- HOV facilities are included with the freeway mainlanes in each corridor.

Exhibit A-11. Travel Time Index—Atlanta Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL							
I-75B NB (I-20 to I-85, 4.045 mi)	1.34	1.25	1.05	1.19	1.17	1.10	1.21
I-75B SB (I-85 to I-20, 4.045 mi)	1.09	1.07	1.15	1.85	1.68	1.20	1.38
CENTRAL-SUBURBAN							
I-75A NB (I-285 South to I-20, 7.720 mi)	1.24	1.18	1.01	1.01	1.01	1.05	1.09
I-75A SB (I-20 to I-285 South., 7.720 mi)	1.00	1.01	1.01	1.13	1.09	1.03	1.05
I-75C NB (I-85 to I-285 North, 9.635 mi)	1.01	1.02	1.01	1.30	1.20	1.05	1.11
I-75C SB (I-285 North to I-85, 9.635 mi)	1.10	1.07	1.02	1.03	1.03	1.03	1.05
I-85A NB (Camp Creek to I-75 South, 4.184 mi)	1.02	1.02	1.01	1.01	1.01	1.02	1.02
I-85A SB I-75 South to Camp Creek, 4.184 mi)	1.00	1.01	1.01	1.04	1.03	1.02	1.02
I-85B NB (I-75 North to Carter Blvd., 13.975 mi)	1.03	1.02	1.02	1.16	1.12	1.04	1.07
I-85B SB (Carter Blvd. to I-75 North, 13.975 mi)	1.15	1.09	1.06	1.35	1.30	1.09	1.20
CORRIDOR AVERAGE	**1.12**	**1.09**	**1.04**	**1.23**	**1.18**	**1.07**	**1.13**

Note: These performance measures represent the portion (39.6 miles) of the total freeway system (306 miles) that contains ITS traffic monitoring sensors.

- I-75B (south of downtown) indicates the effect of directional traffic distribution and system bottlenecks. SB is very directional and NB is more nearly even, with the downtown area (and I-20) creating a queue on I-75NB.
- I-85B is the other freeway with a TTI greater than the average.
- Midday congestion is not a problem.

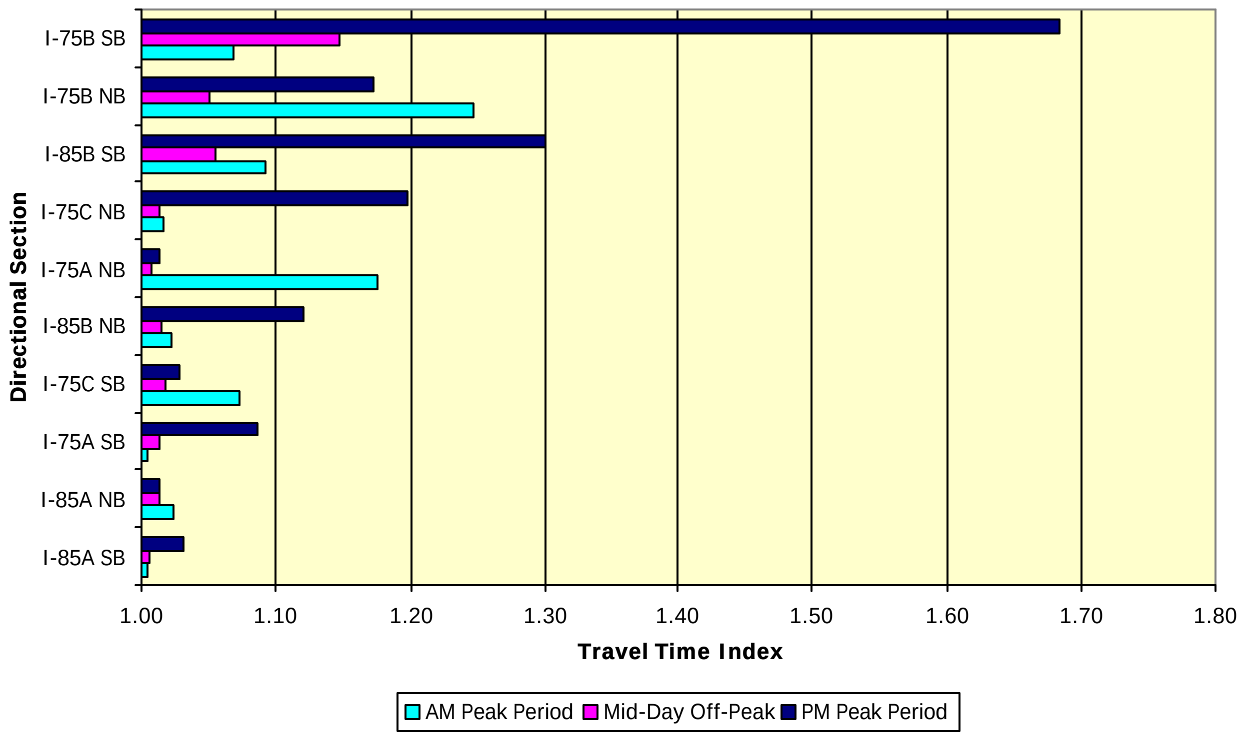


Exhibit A-12. Travel Time Index, by Directional Section

Exhibit A-13. Buffer Index—Atlanta Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL							
I-75B NB (I-20 to I-85, 4.045 mi)	28%	32%	28%	68%	64%	26%	48%
I-75B SB (I-85 to I-20, 4.045 mi)	17%	16%	40%	28%	33%	25%	24%
CENTRAL-SUBURBAN							
I-75A NB (I-285 South to I-20, 7.720 mi)	35%	36%	2%	4%	6%	10%	21%
I-75A SB (I-20 to I-285 South., 7.720 mi)	1%	1%	3%	24%	22%	7%	12%
I-75C NB (I-85 to I-285 North, 9.635 mi)	3%	4%	3%	59%	55%	13%	30%
I-75C SB (I-285 North to I-85, 9.635 mi)	21%	18%	3%	10%	8%	6%	13%
I-85A NB (Camp Creek to I-75 South, 4.184 mi)	9%	7%	5%	5%	5%	5%	6%
I-85A SB I-75 South to Camp Creek, 4.184 mi)	1%	2%	0%	16%	12%	4%	7%
I-85B NB (I-75 North to Carter Blvd., 13.975 mi)	8%	7%	2%	41%	36%	9%	22%
I-85B SB (Carter Blvd. to I-75 North, 13975 mi)	35%	29%	36%	50%	52%	27%	41%
CORRIDOR AVERAGE	**20%**	**19%**	**14%**	**32%**	**31%**	**14%**	**25%**

Note: These performance measures represent the portion (39.6 miles) of the total freeway system (306 miles) that contains ITS traffic monitoring sensors.

- Midday reliability suffers on I-75B and I-85B.
- Reliability is a larger problem in the evening than in the morning.
- Relative to cold climate cities, reliability is not a large problem in Atlanta.
- I-75C NB has a significant reliability difference between morning and evening peaks. Several other freeways also show differences.

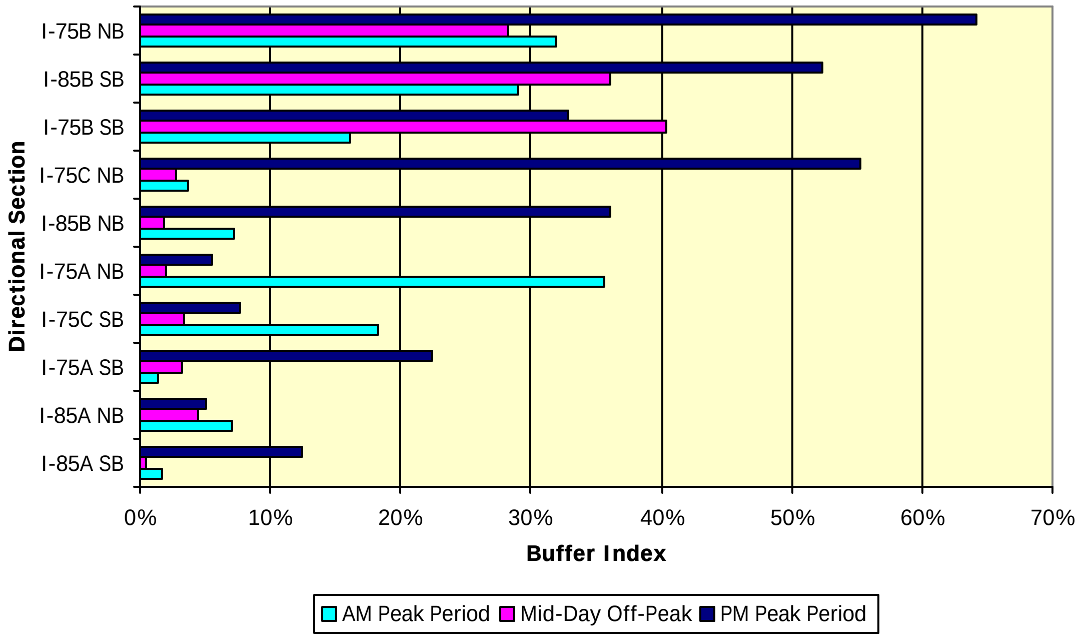


Exhibit A-14. Buffer Index, by Directional Section

Appendix B—Cincinnati, OH

2000 Regional Mobility and Reliability Data

A Supplement to:

Monitoring Urban Roadways: Using Archived Operations Data for Reliability and Mobility Measurement by Texas Transportation Institute and Cambridge Systematics, Inc., May 2001

Cincinnati, OH Findings

- Delay in the off-peak periods is greater than either peak-period.
- Weekend delay is relatively low in relation to weekday delay.
- December weather problems are illustrated in the mobility and reliability measures. Mobility levels declined and there were many days with significantly longer travel times.
- High values of congested travel percentage appear to be related, in part, to many vehicles traveling just below the 60 mph threshold. The early morning hours, in particular, show high-congested travel values, but low time penalties from that "congestion."
- Suburban congestion levels are relatively low, and the system fairly reliable.

Cincinnati, OH Data Source

- Cincinnati's data were supplied from the ARTIMIS system.
- System coverage will expand to cover portions of I-71 in Ohio in 2001.
- Approximately 46 miles of the 174-mile freeway system is included in the archived data system.
- The data was collected primarily using single inductive loops but also through radar and video image processing. Most speeds are calculated and the data reported by direction at 15-minute intervals.
- 93% of both the volume and speed data in the original data archive passed the initial quality control tests.
- The original data records included volume and speed for only 42% of the time periods in 2000.
- After removing data that failed the quality control checks and identifying missing data, only 38% of the possible speed and volume records were found to be usable for further analysis.

Major Study Findings (Why you should read the Final Report)

- It is only 36 pages.
- Local data archiving occurs in some areas but easy accessibility and use of that data is much less widespread. Database management and analytical methods can be somewhat complex, and limited local resources and guidance have also hindered widespread development of easy-to-use data archives. Each area has essentially pursued their own development schedule and scope with funding from local sources. The report, and the associated best practices guide can assist agencies in the data archiving process.
- The mobility and reliability measures used in the report can most efficiently be used for local area trend analysis and analysis of important subjects at the national level. The data are less useful for city-to-city comparisons because of the incomplete ITS coverage and inconsistencies between cities. The report summarizes the measures used in the study and demonstrates how they can be prepared and interpreted.

Exhibit B-1. Trends in Mobility and Reliability Indicators

Indicator	2000	1999	Change
MOBILITY			
Travel Time Index	1.25		
Delay per Capita (hours)	2.0		
Percent Congested Travel	61%		
RELIABILITY			
Buffer Index	37%		
Misery Rate	30%		
Percent Variation	31%		

Notes: [1]These performance measures represent the portion (46.1 miles) of the total freeway system (174 miles) that contains ITS traffic monitoring sensors.

[2]All statistics reported in this exhibit are peak period averages for all weekdays in the year indicated (no holidays included).

[3]This exhibit will be used to illustrate annual trends once we have more than one year of data.

Data analysis by Texas Transportation Institute and Cambridge Systematics, Inc.
Data provided by ARTIMIS and Kentucky Transportation Cabinet.

Travel Time Index—A ratio of peak travel rate to a free-flow travel rate. A TTI of 1.3 indicates a 20-minute off-peak trip would take 26 minutes in the peak.

Delay per Capita—Estimate of the annual delay (in hours) per person in the urban area. Until a larger percentage of the system is instrumented, this value will be artificially low.

Percent Congested Travel—The percentage of vehicle-miles of travel that occur below 60 mph.

Buffer Index—The percentage of time above the average necessary to allow travelers to arrive on time for 95% of trips. The difference between the 95th and average travel rate divided by the average travel rate.

Misery Rate—The length of delay for the most congested 20% of the trips. The average travel rate is subtracted from the average rate for the slowest 20% of the trips. The Misery Rate is a percentage of extra time needed for the worst 20% of the trips.

Percent Variation—The amount of extra time needed to be on time for 85% of the trips. Calculated as the standard deviation divided by the average travel rate.

An exhibit will be inserted here to illustrate annual trends once we have more than 1 year of data.

Exhibit B-2. Cincinnati, Ohio/Kentucky Regional Area
(Source: SmarTraveler, http://www.smartraveler.com)

Routes included in performance measure estimates:

KY I-71/I-75 (NB 11.2 mi, SB 11.2 mi)
KY I-275 (EB 10.9 mi, WB 10.9 mi)
OH I-75 (NB 15.6 mi, SB 15.6 mi)
OH I-275 (EB 8.4 mi, WB 8.4 mi)

Where and When Delay Occurs

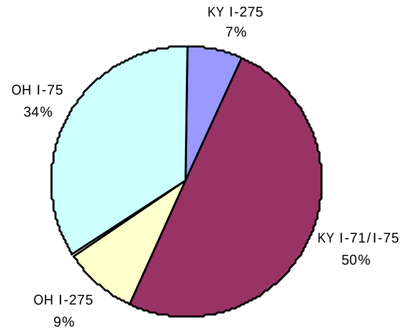


Exhibit B-3. Delay by Roadway

- ♦ 57% of delay on instrumented freeway sections occurs in Kentucky.
- ♦ Delay on I-275 is evenly split between states.

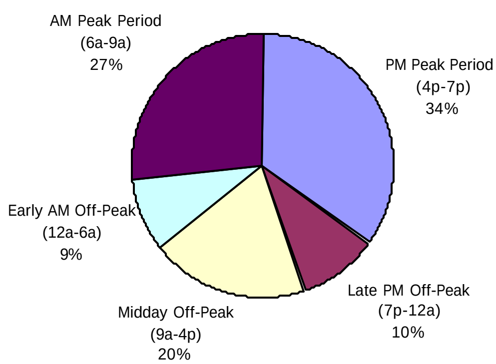


Exhibit B-4. Delay by Time of Day

- ♦ The off-peaks total more delay than either peak.
- ♦ Midday off-peak delay approaches the peak period delay but is spread over 7 hours.

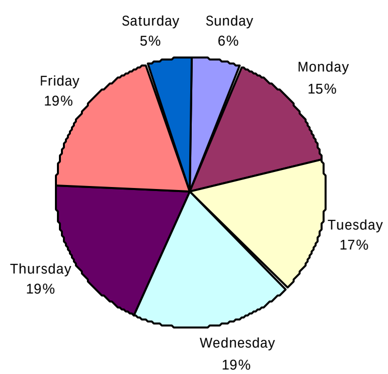
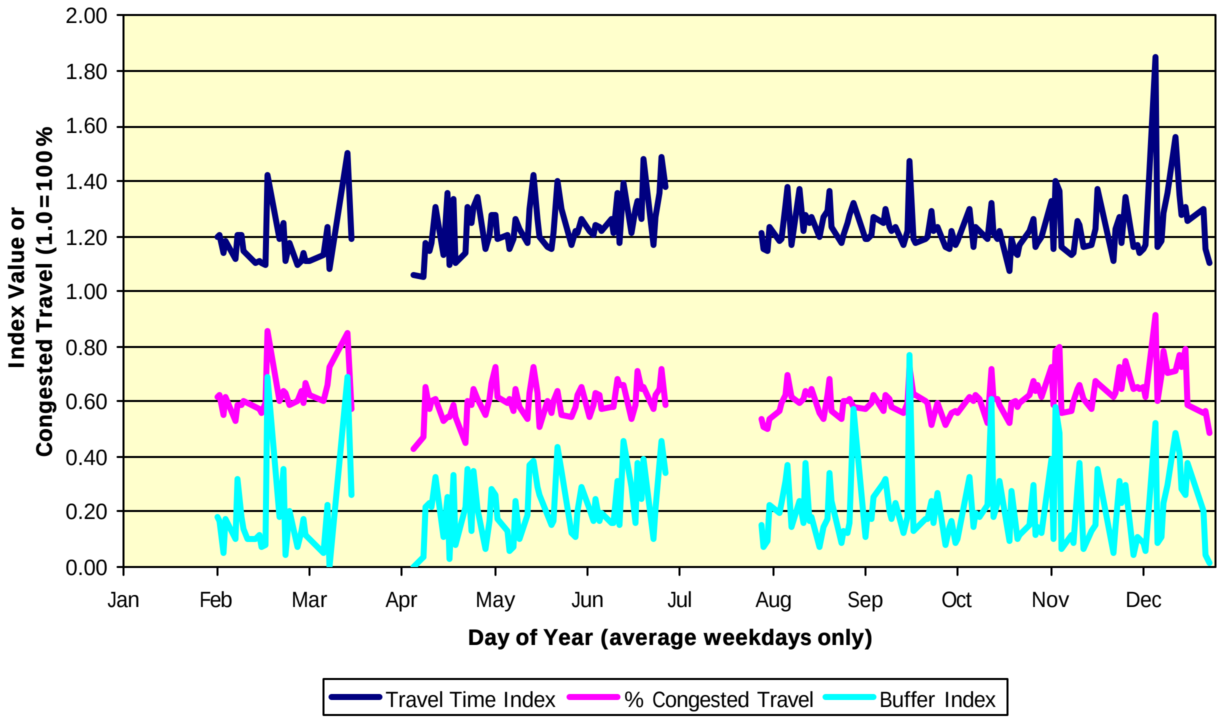


Exhibit B-5. Delay by Day of Week

- ♦ The last 3 days of the work week have about the same delay.
- ♦ Weekend delay is relatively low—less than any weekday.



Note: Trend lines will be added to this graph when data from a sufficient time has been collected. Until multiple years of data are analyzed, the apparent trend may only be a seasonal variation in travel conditions.

Exhibit B-6. Mobility and Reliability Measures by Day of the Year

- There are several day "spikes" that are not reflected in the average congestion measures.
- There are at least 6 days with time penalties twice the average (TRI over 1.50).
- February and early-March had relatively low congestion.
- Weather problems in December created delay and reliability problems.
- Data are missing from March and July.

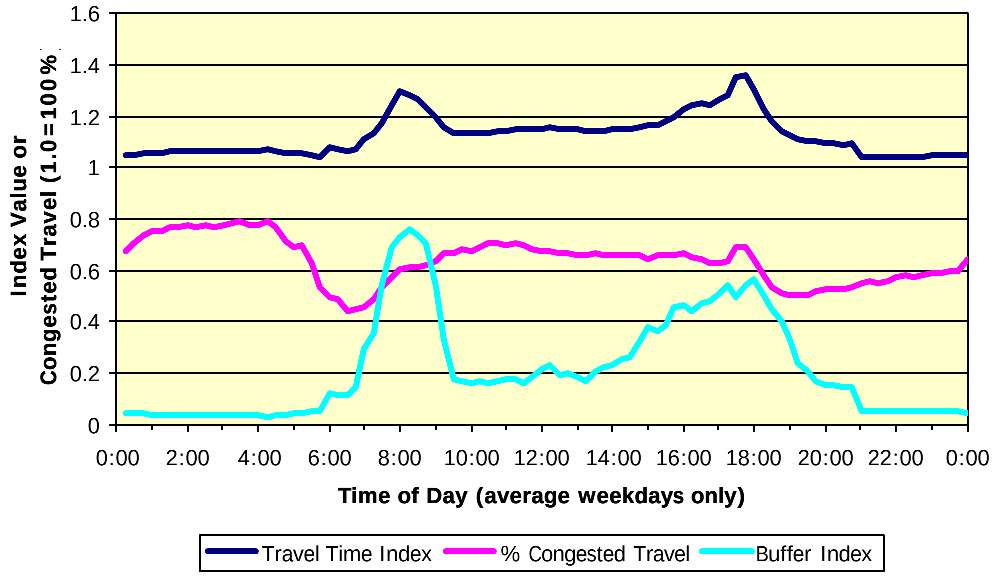


Exhibit B-7. Mobility and Reliability Measures by Time of an Average Day

- ♦ The TRI follows a typical bi-modal distribution—higher peak period values—but the midday values are higher than might be expected.
- ♦ The congested travel graph indicates relatively high off-peak congestion levels. This may be a function of lower urban speed limits. As the morning peak approaches, motorists appear to travel slightly faster to "beat the crowd." Congested travel grows again in the midday.
- ♦ Morning reliability problems are significant over a relatively short period while afternoon values are not as high but last for more hours.

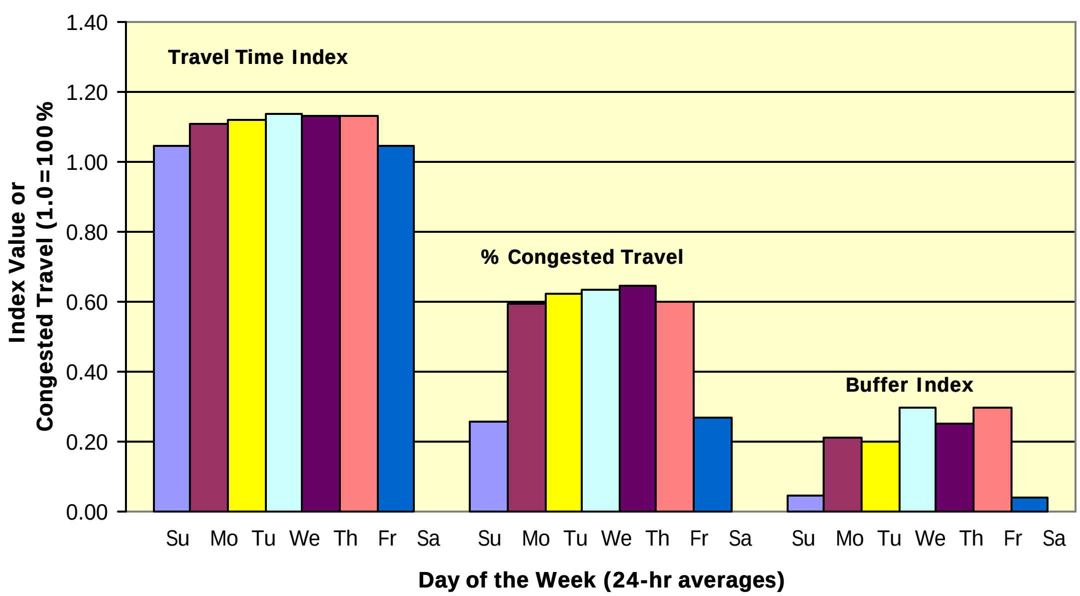


Exhibit B-8. Mobility and Reliability Measures by Day of an Average Week

- ♦ Wednesday and Friday are the least reliable days of the week.
- ♦ Weekend days are very reliable.
- ♦ Congestion levels are about the same for all weekdays.
- ♦ For an area with relatively low TRI values, the percent of congested travel is relatively high.

2000 MOBILITY AND RELIABILITY REPORT—
BY DIRECTIONAL SECTION, CINCINNATI, OH/KY

Exhibit B-9. Top Ten List—Most Congested Peak Periods

Rank	Directional Section	Date	Time Period	Travel Time Index
1	Kentucky I-71/I-75 NB	August 14, 2000	AM Peak Period	3.25
2	Kentucky I-71/I-75 SB	December 27, 2000	PM Peak Period	3.13
3	Kentucky I-71/I-75 NB	August 24, 2000	AM Peak Period	3.11
4	Kentucky I-71/I-75 NB	June 20, 2000	AM Peak Period	3.05
5	Kentucky I-71/I-75 NB	August 23, 2000	AM Peak Period	3.02
6	Kentucky I-71/I-75 NB	August 22, 2000	AM Peak Period	3.00
7	Kentucky I-71/I-75 NB	September 11, 2000	AM Peak Period	2.60
8	Kentucky I-71/I-75 NB	September 27, 2000	AM Peak Period	2.56
9	Kentucky I-71/I-75 NB	December 11, 2000	PM Peak Period	2.53
10	Kentucky I-71/I-75 SB	April 20, 2000	PM Peak Period	2.52

Exhibit B-10. Top Ten List—Least Reliable Peak Periods

Rank	Directional Section	Date	Time Period	Buffer Index
1	Kentucky I-71/I-75 NB	April 18, 2000	AM Peak Period	547%
2	Kentucky I-275 WB	September 20, 2000	PM Peak Period	438%
3	Kentucky I-71/I-75 NB	December 27, 2000	PM Peak Period	399%
4	Ohio, I-275 EB	September 20, 2000	PM Peak Period	329%
5	Kentucky I-71/I-75 NB	August 22, 2000	AM Peak Period	308%
6	Kentucky I-71/I-75 NB	September 25, 2000	AM Peak Period	287%
7	Kentucky I-275 EB	April 25, 2000	PM Peak Period	267%
8	Kentucky I-71/I-75 NB	November 20, 2000	PM Peak Period	265%
9	Ohio, I-275 EB	February 23, 2000	AM Peak Period	265%
10	Kentucky I-71/I-75 SB	June 20, 2000	AM Peak Period	263%

- The Kentucky system elements have most of the worst days.
- August and September had half of the days on these two lists.
- The morning period had more congestion problems than the evening, but reliability problems were evenly split.
- I-71/I-75 NB has 13 of the 20 most significant problem periods.
- No midday or off-peak periods are included in the Top Ten Lists.

Exhibit B-11. Travel Time Index—Cincinnati Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL-SUBURBAN							
Kentucky I-71/I-75, NB (US 42 to Covington, 11.2 mi)	1.82	1.62	1.32	1.21	1.25	1.30	1.43
Kentucky I-71/I-75, SB (US 42 to Covington, 11.2 mi)	1.10	1.12	1.25	1.47	1.42	1.23	1.27
Ohio I-75, NB (I-71 [CBD] to I-275, 15.6 mi)	1.15	1.12	1.12	1.41	1.30	1.13	1.21
Ohio I-75, SB (I-71 [CBD] to I-275, 15.6 mi)	1.41	1.29	1.21	1.40	1.35	1.22	1.32
SUBURBAN							
Kentucky I-275, EB (Ohio River to I-71/I75, 10.9 mi)	1.07	1.06	1.04	1.05	1.07	1.05	1.06
Kentucky I-275, WB (Ohio River to I-71/75, 10.9 mi)	1.01	1.01	1.01	1.01	1.02	1.01	1.02
Ohio I-275, EB (SR-4 to I-71, 8.4 mi)	1.14	1.08	1.03	1.24	1.14	1.06	1.11
Ohio I-275, WB (SR-4 to I-71, 8.4 mi)	1.05	1.03	1.01	1.20	1.12	1.04	1.08
CORRIDOR AVERAGE	**1.28**	**1.20**	**1.16**	**1.36**	**1.29**	**1.17**	**1.25**

Note: These performance measures represent the portion (46.1 miles) of the total freeway system (174 miles) that contains ITS traffic monitoring sensors.

- There is less congestion in the Suburban corridors.
- Congestion levels are higher in the afternoon.
- I-71/I-75 exhibits a directional congestion problem, while I-75 is more balanced.
- The afternoon peak period congestion pattern is more balanced for each facility than the morning pattern.

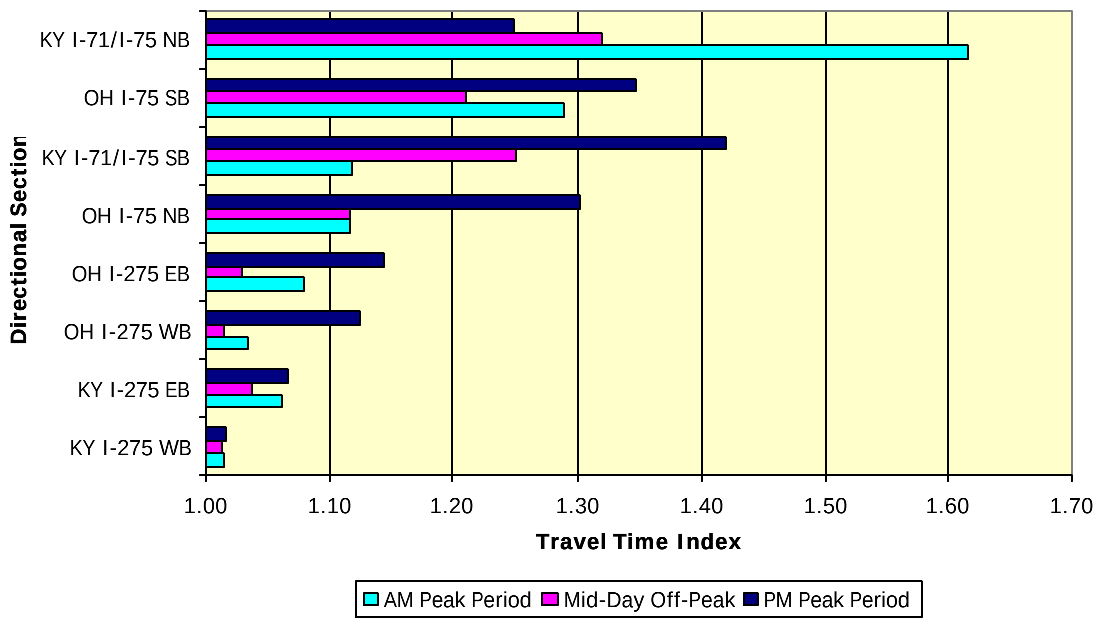


Exhibit B-12. Travel Time Index, by Directional Section

Exhibit B-13. Buffer Index—Cincinnati Annual Summary, Year 2000

CORRIDOR	Morning		Midday (9a-4p)	Afternoon		Daily (24 hr)	Avg. Peak Period (am & pm)
	Peak Hour (7a-8a)	Peak Period (6a-9a)		Peak Hour (5p-6p)	Peak Period (4p-7p)		
CENTRAL-SUBURBAN							
Kentucky I-71/I-75, NB (US 42 to Covington, 11.2 mi)	74%	77%	49%	39%	53%	42%	65%
Kentucky I-71/I-75, SB (US 42 to Covington, 11.2 mi)	7%	9%	29%	70%	54%	26%	32%
Ohio I-75, NB (I-71 [CBD] to I-275, 15.6 mi)	27%	22%	14%	50%	45%	19%	34%
Ohio I-75, SB (I-71 [CBD] to I-275, 15.6 mi)	34%	34%	25%	43%	46%	25%	40%
SUBURBAN							
Kentucky I-275, EB (Ohio River to I-71/I75, 10.9 mi)	22%	8%	6%	5%	1%	5%	5%
Kentucky I-275, WB (Ohio River to I-71/75, 10.9 mi)	4%	3%	4%	3%	3%	4%	3%
Ohio I-275, EB (SR-4 to I-71, 8.4 mi)	39%	26%	3%	54%	48%	18%	37%
Ohio I-275, WB (SR-4 to I-71, 8.4 mi)	26%	15%	2%	55%	50%	15%	33%
CORRIDOR AVERAGE	**32%**	**29%**	**20%**	**47%**	**46%**	**22%**	**37%**

Note: These performance measures represent the portion (46.1 miles) of the total freeway system (174 miles) that contains ITS traffic monitoring sensors.

- Most of the reliability problems are in the evening peak with the exception of I-71/I-75 NB.
- I-71/I-75 has the most significant reliability problems.

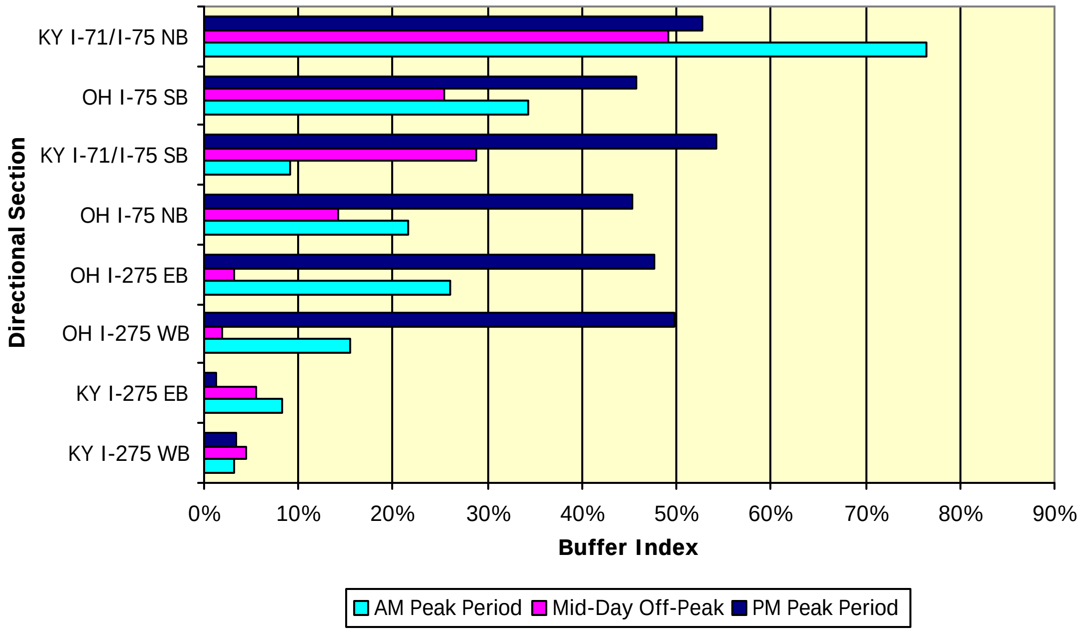


Exhibit B-14. Buffer Index, by Directional Section

Appendix C—Detroit, MI

2000 Regional Mobility and Reliability Data

A Supplement to:

Monitoring Urban Roadways: Using Archived Operations Data for Reliability and Mobility Measurement by Texas Transportation Institute and Cambridge Systematics, Inc., May 2001

Detroit, MI Findings

- A relatively short section of I-96 was 1/3 of the estimated delay from the instrumented freeways.
- The peak periods contain more than 60% of the delay.
- Weekend delay exceeds the delay for any weekday.
- Weather problems in January and December 2000 are reflected in lower mobility and reliability measures.
- A 3 a.m. peak is identified in the daily congestion graph. Reliability is not significantly affected, but it does appear that activity near the instrumented freeways causes an increase in travel and a decrease in speed.

Detroit, MI Data Source

- Detroit's data were supplied from the Michigan ITS Center, operated by the Michigan Department of Transportation. A large portion of the Detroit area's freeways have been instrumented. However, the "core system" in the vicinity of the CBD has been offline for most of the year road reconstruction damaged the communication lines and they have not yet been repaired. The data used in this study excluded the "core system".
- Detector spacing in the core system is 1/3 mile. In the suburbs spacing increases dramatically, and can be up to 2 miles. Double loops are used throughout.
- Approximately 117 of the more than 283-mile freeway system is included in the archived data system. The data was collected using double inductive loops and the data is reported by lane at 1-minute intervals.
- 99.7% of both the volume and speed data in the original data archive passed the initial quality control tests.
- The original data records included data records for 67% of volume and 65% of speed data the time periods in 2000.
- With almost all of the original data passing the quality control checks, 67% of the volume records and 65% of the speed data was usable for analysis.

Major Study Findings (Why you should read the Final Report)

- It is only 36 pages.
- Local data archiving occurs in some areas but easy accessibility and use of that data is much less widespread. Database management and analytical methods can be somewhat complex, and limited local resources and guidance have also hindered widespread development of easy-to-use data archives. Each area has essentially pursued their own development schedule and scope with funding from local sources. The report, and the associated best practices guide can assist agencies in the data archiving process.
- The mobility and reliability measures used in the report can most efficiently be used for local area trend analysis and analysis of important subjects at the national level. The data are less useful for city-to-city comparisons because of the incomplete ITS coverage and inconsistencies between cities. The report summarizes the measures used in the study and demonstrates how they can be prepared and interpreted.

Exhibit C-1. Trends in Mobility and Reliability Indicators

Indicator	2000	1999	Change
MOBILITY			
Travel Time Index	1.12		
Delay per Capita (hours)	0.9		
Percent Congested Travel	19%		
RELIABILITY			
Buffer Index	31%		
Misery Rate	21%		
Percent Variation	27%		

Notes: [1]These performance measures represent the portion (117.0 miles) of the total freeway system (283 miles) that contains ITS traffic monitoring sensors.

[2]All statistics reported in this exhibit are peak period averages for all weekdays in the year indicated (no holidays included).

[3]This exhibit will be used to illustrate annual trends once we have more than one year of data.

Data analysis by Texas Transportation Institute and Cambridge Systematics, Inc.
Data provided by Michigan DOT.

Travel Time Index—A ratio of peak travel rate to a free-flow travel rate. A TTI of 1.3 indicates a 20-minute off-peak trip would take 26 minutes in the peak.

Delay per Capita—Estimate of the annual delay (in hours) per person in the urban area. Until a larger percentage of the system is instrumented, this value will be artificially low.

Percent Congested Travel—The percentage of vehicle-miles of travel that occur below 60 mph.

Buffer Index—The percentage of time above the average necessary to allow travelers to arrive on time for 95% of trips. The difference between the 95th and average travel rate divided by the average travel rate.

Misery Rate—The length of delay for the most congested 20% of the trips. The average travel rate is subtracted from the average rate for the slowest 20% of the trips. The Misery Rate is a percentage of extra time needed for the worst 20% of the trips.

Percent Variation—The amount of extra time needed to be on time for 85% of the trips. Calculated as the standard deviation divided by the average travel rate.

An exhibit will be inserted here to illustrate annual trends once we have more than 1 year of data.

Exhibit C-2. Detroit, Michigan Regional Area
(Source: SmarTraveler, http://www.smartraveler.com)

Routes included in performance measure estimates:

I-75 (NB 18.825 mi, SB 18.825 mi)
I-94 (EB 34.033 mi, WB 34.033 mi)
I-96 (EB 22.508 mi, WB 22.508 mi)
I-696 (EB 25.484 mi, WB 25.484 mi)
MI 10 (NB 2.405 mi, SB 2.405 mi)
MI 39 (NB 13.7 mi, SB 13.7 mi)

Where and When Delay Occurs

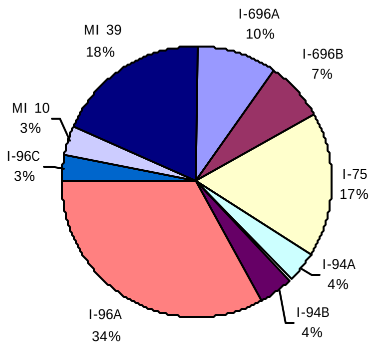


Exhibit C-3. Delay by Roadway

- ♦ 1/3 of the delay is on a relatively short section of I-96.
- ♦ MI 39 and I-75 also have significant portions of delay.

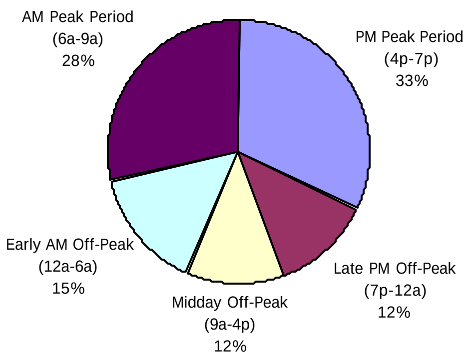


Exhibit C-4. Delay by Time of Day

- ♦ More than 60% of delay is in the peak periods.
- ♦ Midday delay is not a significant problem.

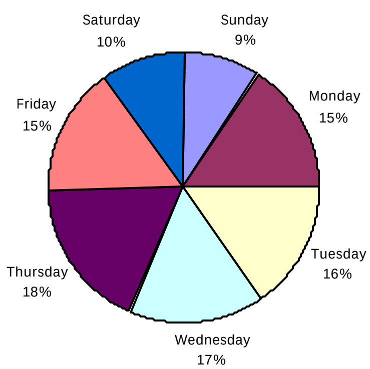
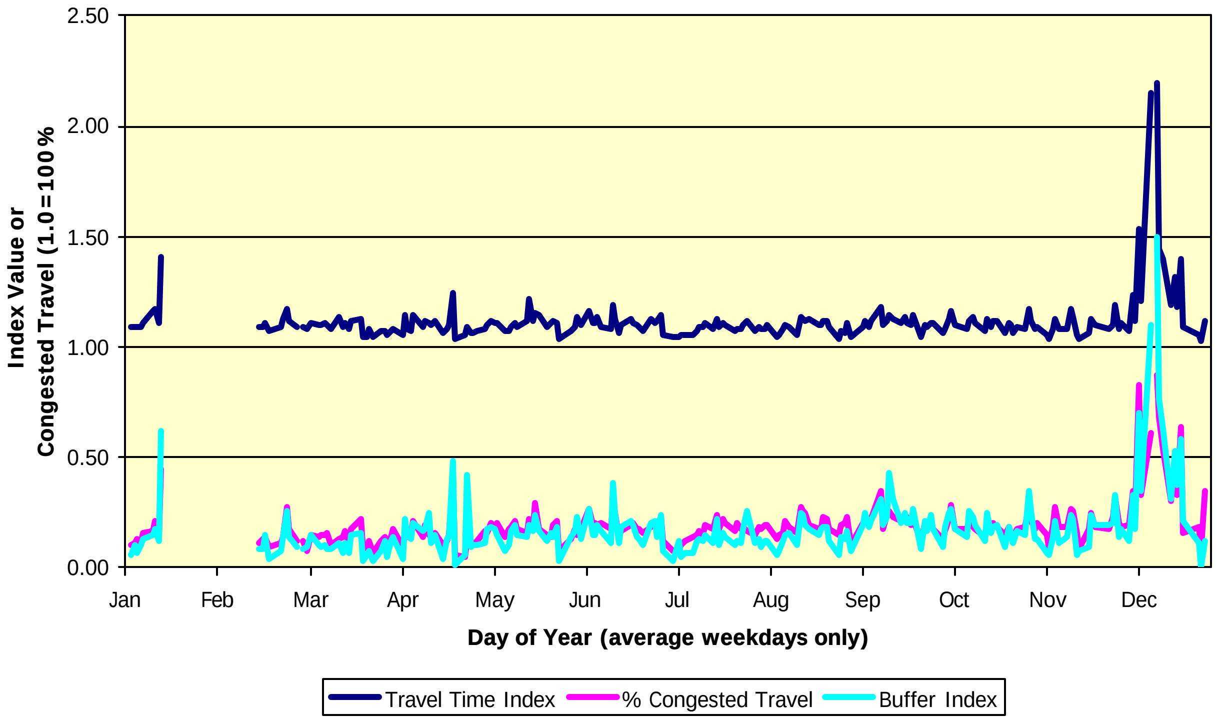


Exhibit C-5. Delay by Day of Week

- ♦ Delay grows during the weekdays to a peak of 18% on Thursday.
- ♦ The two weekend days have more delay combined than any weekday.



Note: Trend lines will be added to this graph when data from a sufficient time has been collected. Until multiple years of data are analyzed, the apparent trend may only be a seasonal variation in travel conditions.

Exhibit C-6. Mobility and Reliability Measures by Day of the Year

- Weather related problems in January and December are responsible for the most significant delays.
- Congestion levels and reliability are similar through the year. The December weather problems are responsible for the apparent upward trend.
- Data were not available in January and February.

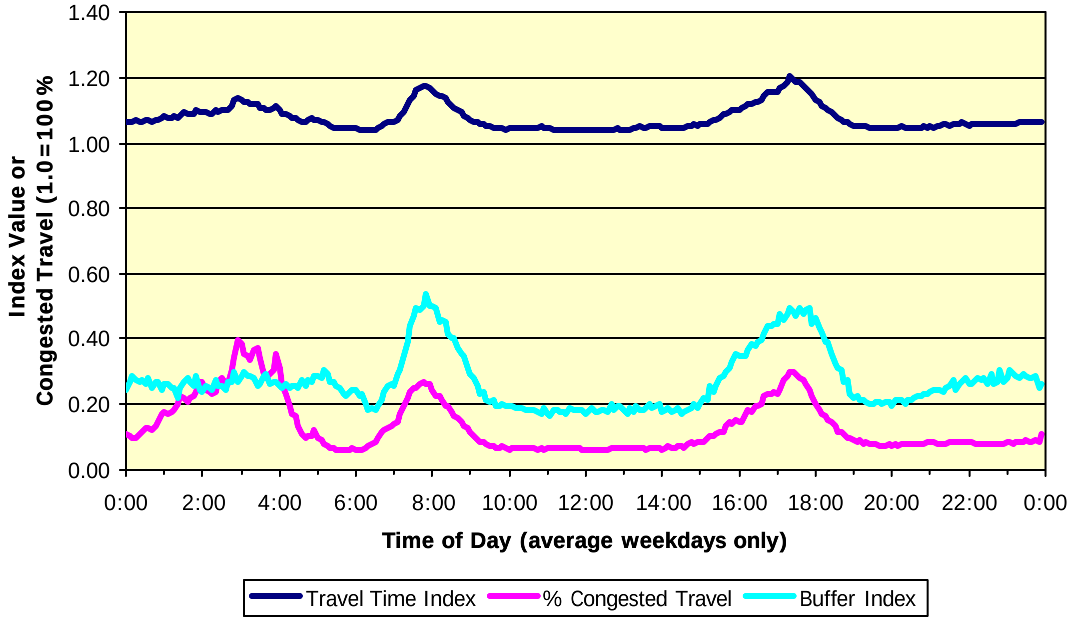


Exhibit C-7. Mobility and Reliability Measures by Time of an Average Day

- Congestion levels follow the expected trends except for the peak at 3 a.m.
- Reliability is lowest during the peaks.
- The 3 a.m. "peak" is reflected in both the congested travel and TTI measures. This may be the effect of a shift change near some of the instrumented freeways.

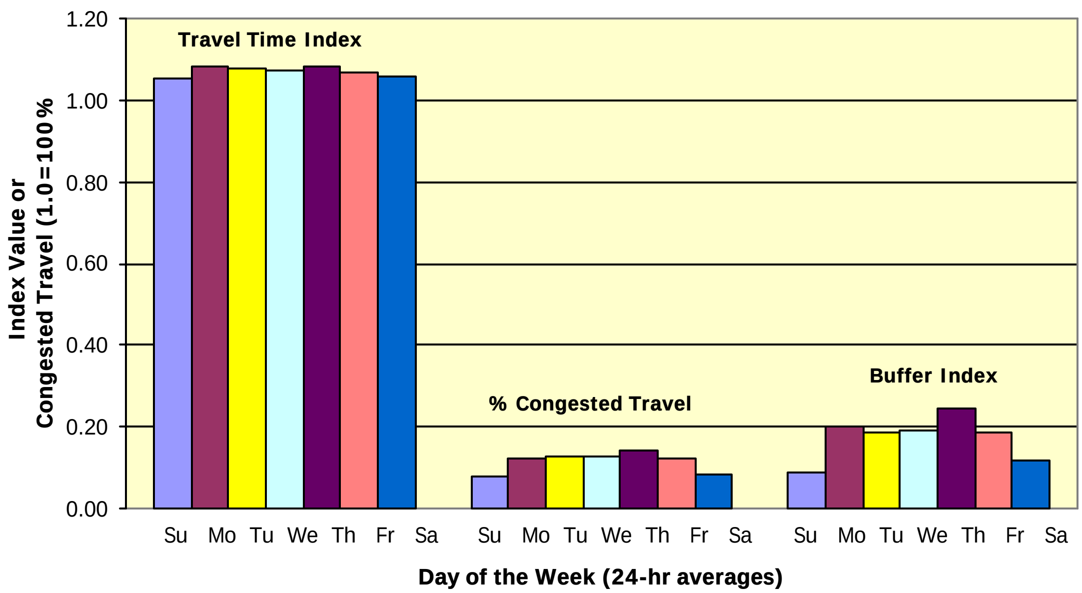


Exhibit C-8. Mobility and Reliability Measures by Day of an Average Week

- Thursday is the most unreliable day.
- Weekend days are relatively reliable.
- The average percent of congested travel remains relatively low.

2000 MOBILITY AND RELIABILITY REPORT—
BY DIRECTIONAL SECTION, DETROIT, MICHIGAN

Exhibit C-9. Top Ten List—Most Congested Peak Periods

Rank	Directional Section	Date	Time Period	Travel Time Index
1	MI 10 NB	December 11, 2000	PM Peak Period	5.66
2	I-96A WB	December 11, 2000	PM Peak Period	5.19
3	I-96A EB	December 11, 2000	PM Peak Period	4.53
4	I-75 NB	December 11, 2000	PM Peak Period	4.25
5	I-696A WB	December 11, 2000	PM Peak Period	4.07
6	I-696A WB	December 13, 2000	PM Peak Period	3.85
7	MI 10 NB	December 13, 2000	PM Peak Period	3.82
8	I-94B EB	December 11, 2000	PM Peak Period	3.59
9	I-75 NB	May 16, 2000	PM Peak Period	3.58
10	I-696A EB	December 11, 2000	PM Peak Period	3.58

Exhibit C-10. Top Ten List—Least Reliable Peak Periods

Rank	Directional Section	Date	Time Period	Buffer Index
1	MI 10 NB	December 11, 2000	PM Peak Period	752%
2	MI 10 NB	December 13, 2000	PM Peak Period	609%
3	I-94B WB	December 13, 2000	AM Peak Period	458%
4	I-96A WB	December 11, 2000	PM Peak Period	436%
5	I-94B WB	June 21, 2000	AM Peak Period	394%
6	I-75 NB	December 11, 2000	PM Peak Period	362%
7	MI 10 SB	December 13, 2000	PM Peak Period	359%
8	I-96A EB	December 11, 2000	PM Peak Period	355%
9	I-75 NB	December 14, 2000	AM Peak Period	354%
10	I-94B EB	December 11, 2000	PM Peak Period	336%

- Weather problems in December presented a significant congestion and reliability concern.
- Several roadways are represented in the top 10 lists due to the areawide nature of weather problems.

Exhibit C-11. Travel Time Index—Detroit Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL							
I-94B, EB (M-10 to I-696, 13.037 mi)	1.01	1.02	1.04	1.10	1.07	1.04	1.04
I-94B, WB (I-696 to M-10, 13.037 mi)	1.03	1.03	1.01	1.01	1.01	1.02	1.02
CENTRAL-SUBURBAN							
I-94A, EB (I-275 to M-10, 20.996 mi)	1.04	1.04	1.01	1.01	1.01	1.02	1.03
I-94A, WB (M-10 to I-275, 20.996)	1.01	1.01	1.02	1.16	1.11	1.04	1.06
I-96C, EB (I-96 to I-94, 16.704 mi)	1.07	1.07	1.01	1.02	1.01	1.02	1.04
I-96C, WB (I-94 to I-96, 16.704 mi)	1.01	1.01	1.01	1.08	1.05	1.02	1.03
SUBURBAN							
I-696A, EB (I-96 to I-75, 17.095 mi)	1.07	1.06	1.02	1.26	1.17	1.06	1.12
I-696A, WB (I-75 to I-96, 17.095 mi)	1.22	1.13	1.02	1.29	1.20	1.08	1.16
I-696B, EB (I-75 to M-3, 8.389 mi)	1.01	1.01	1.02	1.26	1.17	1.06	1.09
I-696B, WB (M-3 to I-75, 8.389 mi)	1.15	1.15	1.01	1.02	1.02	1.05	1.08
I-75, NB (I-696 to Auburn Hills, 18.825 mi)	1.23	1.18	1.07	1.35	1.29	1.13	1.24
I-75, SB (Auburn Hills to I-696, 18.825 mi)	1.25	1.21	1.06	1.17	1.15	1.10	1.18
I-96A, EB (Exit 160 to I-96, 5.804 mi)	1.33	1.33	1.28	1.32	1.28	1.30	1.31
I-96A, WB (I-96 to Exit 160, 5.804 mi)	1.09	1.08	1.06	1.24	1.19	1.11	1.13
MI 10, NB (9-Mile Road to I-696, 2.405 mi)	1.12	1.07	1.01	1.07	1.05	1.03	1.06
MI 10, SB (I-696 to 9-Mile Road, 2.405 mi)	1.01	1.01	1.01	1.07	1.03	1.02	1.02
MI 39, NB (I-94 to I-96, 13.7 mi)	1.12	1.11	1.12	1.26	1.22	1.15	1.16
MI 39, SB (I-96 to I-94, 13.7 mi)	1.24	1.22	1.01	1.17	1.11	1.08	1.17
CORRIDOR AVERAGE	**1.12**	**1.11**	**1.04**	**1.17**	**1.13**	**1.07**	**1.12**

Note: These performance measures represent the portion (117.0 miles) of the total freeway system (283 miles) that contains ITS traffic monitoring sensors.

- Congestion levels in the Central and Central-Suburban areas are low.
- Midday congestion is a problem only on EB I-96 in the suburbs.
- Only two roadways have travel rate index values greater than 1.2.

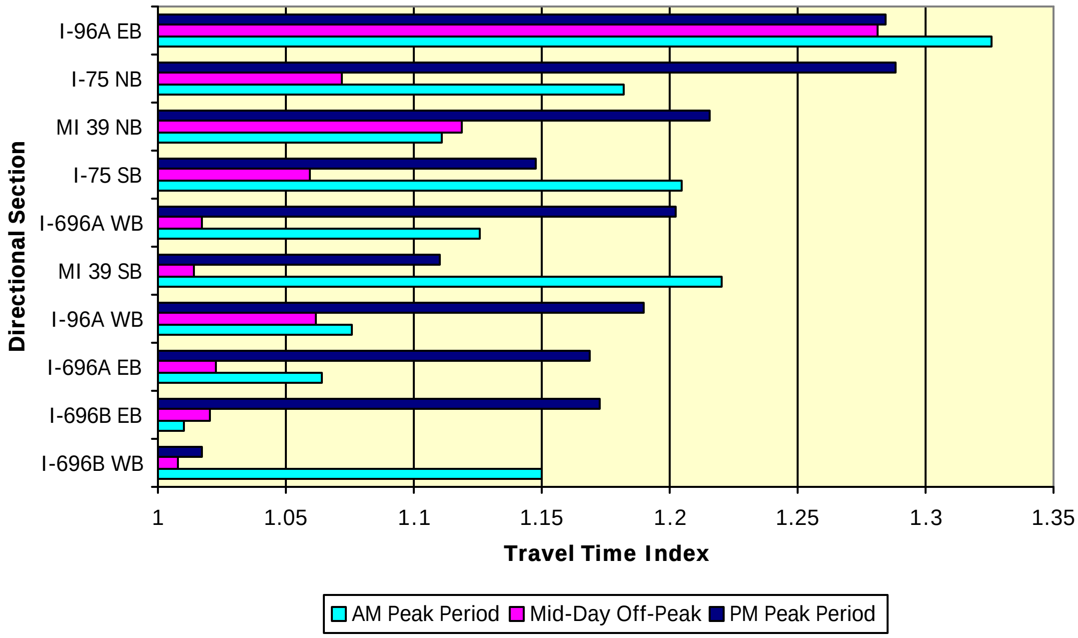


Exhibit C-12. Travel Time Index, by Ten Most Congested Directional Sections

- The greatest directional imbalance in congestion is on I-696B—a facility with a loop numerical designation.

Exhibit C-13. Buffer Index—Detroit Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL							
I-94B, EB (M-10 to I-696, 13.037 mi)	0%	0%	0%	33%	16%	2%	8%
I-94B, WB (I-696 to M-10, 13.037 mi)	0%	0%	0%	0%	0%	0%	0%
CENTRAL-SUBURBAN							
I-94A, EB (I-275 to M-10, 20.996 mi)	22%	16%	0%	8%	5%	4%	11%
I-94A, WB (M-10 to I-275, 20.996)	2%	3%	6%	37%	33%	15%	18%
I-96C, EB (I-96 to I-94, 16.704 mi)	30%	25%	0%	11%	7%	9%	16%
I-96C, WB I-94 to I-96, 16.704 mi)	7%	5%	0%	22%	18%	6%	12%
SUBURBAN							
I-696A, EB (I-96 to I-75, 17.095 mi)	36%	32%	13%	48%	45%	22%	38%
I-696A, WB (I-75 to I-96, 17.095 mi)	33%	31%	3%	55%	54%	21%	42%
I-696B, EB (I-75 to M-3, 8.389 mi)	3%	4%	5%	51%	51%	16%	27%
I-696B, WB (M-3 to I-75, 8.389 mi)	49%	46%	0%	1%	0%	12%	23%
I-75, NB (I-696 to Auburn Hills, 18.825 mi)	74%	57%	34%	62%	62%	40%	59%
I-75, SB (Auburn Hills to I-696, 18.825 mi)	81%	70%	20%	32%	32%	31%	51%
I-96A, EB (Exit 160 to I-96, 5.804 mi)	59%	60%	62%	58%	61%	62%	61%
I-96A, WB (I-96 to Exit 160, 5.804 mi)	26%	24%	18%	47%	45%	36%	35%
MI 10, NB (9-Mile Road to I-696, 2.405 mi)	32%	30%	0%	28%	18%	12%	24%
MI 10, SB (I-696 to 9-Mile Road, 2.405 mi)	0%	0%	0%	40%	4%	5%	2%
MI 39, NB (I-94 to I-96, 13.7 mi)	26%	19%	12%	26%	27%	18%	23%
MI 39, SB (I-96 to I-94, 13.7 mi)	54%	50%	3%	40%	39%	21%	44%
CORRIDOR AVERAGE	**34%**	**30%**	**10%**	**35%**	**32%**	**19%**	**31%**

Note: These performance measures represent the portion (117.0 miles) of the total freeway system (283 miles) that contains ITS traffic monitoring sensors.

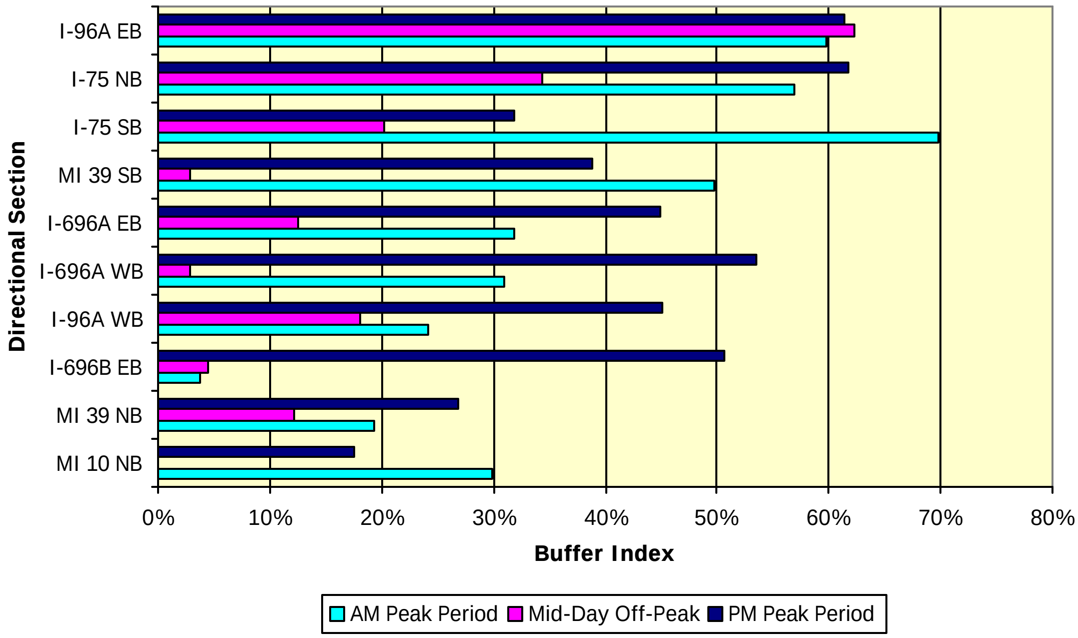


Exhibit C-14. Buffer Index, by Ten Most Congested Directional Sections

- Roadways in the Central and Central-Suburban areas are relatively reliable.
- Peak periods are less reliable than other times of the day.
- Midday reliability is a problem only on I-96A.
- The least reliable roadways are I-75 and I-96A.
- The evening peaks are usually less reliable than morning or midday.

Appendix D—Hampton Roads, VA

2000 Regional Mobility and Reliability Data

A Supplement to:

Monitoring Urban Roadways: Using Archived Operations Data for Reliability and Mobility Measurement by Texas Transportation Institute and Cambridge Systematics, Inc., May 2001

Hampton Roads, VA Findings

- Midday off-peak congestion is a more significant element of total delay than either peak period—almost twice as much as the morning peak.
- Port-related activities—principally ship arrivals—influence congestion patterns on the nearby-instrumented freeways.
- Speeds just below 60 mph contribute to a pattern of high percent-congested travel values and low Travel Time Index values (60 mph is the congestion threshold below which congestion is considered to occur).
- Weekend delays are equivalent to one weekday.
- While there is some variation on the TTI, there are many significant “spikes” in the Buffer Index, indicating reliability problems. Average reliability levels, however, are good.

Hampton Roads, VA Data Source

- Approximately 19 miles of the more than 159-mile freeway system is included in the archived data system. The Virginia Transportation Research Council and Virginia DOT provided the data.
- Data collected was primarily using double inductive loops. Direct speed estimates are obtained and the data reported by lane at 2-minute intervals.
- 90% of both the volume and speed data in the original data archive passed the initial quality control tests.
- The original data records included 67% of the volume and 48% of the speed data for time periods in 2000.
- After removing data that failed the quality control checks and identifying missing data, 48% of the possible speed data and 36% of the volume records were found to be usable for further analysis.

Major Study Findings (Why you should read the Final Report)

- It is only 36 pages.
- Local data archiving occurs in some areas but easy accessibility and use of that data is much less widespread. Database management and analytical methods can be somewhat complex, and limited local resources and guidance have also hindered widespread development of easy-to-use data archives. Each area has essentially pursued their own development schedule and scope with funding from local sources. The report, and the associated best practices guide can assist agencies in the data archiving process.
- The mobility and reliability measures used in the report can most efficiently be used for local area trend analysis and analysis of important subjects at the national level. The data are less useful for city-to-city comparisons because of the incomplete ITS coverage and inconsistencies between cities. The report summarizes the measures used in the study and demonstrates how they can be prepared and interpreted.

Exhibit D-1. Trends in Mobility and Reliability Indicators

Indicator	2000	1999	Change
MOBILITY			
Travel Time Index	1.07		
Delay per Capita (hours)	2.2		
Percent Congested Travel	30%		
RELIABILITY			
Buffer Index	30%		
Misery Rate	16%		
Percent Variation	37%		

Notes: [1]These performance measures represent the portion (19.7 miles) of the total freeway system (159 miles) that contains ITS traffic monitoring sensors.

[2]All statistics reported in this exhibit are peak period averages for all weekdays in the year indicated (no holidays included).

[3]This exhibit will be used to illustrate annual trends once we have more than one year of data.

Data analysis by Texas Transportation Institute and Cambridge Systematics, Inc.
Data provided by Virginia Transportation Research Council and Virginia DOT.

Travel Time Index—A ratio of peak travel rate to a free-flow travel rate. A TTI of 1.3 indicates a 20-minute off-peak trip would take 26 minutes in the peak.

Delay per Capita—Estimate of the annual delay (in hours) per person in the urban area. Until a larger percentage of the system is instrumented, this value will be artificially low.

Percent Congested Travel—The percentage of vehicle-miles of travel that occur below 60 mph.

Buffer Index—The percentage of time above the average necessary to allow travelers to arrive on time for 95% of trips. The difference between the 95th and average travel rate divided by the average travel rate.

Misery Rate—The length of delay for the most congested 20% of the trips. The average travel rate is subtracted from the average rate for the slowest 20% of the trips. The Misery Rate is a percentage of extra time needed for the worst 20% of the trips.

Percent Variation—The amount of extra time needed to be on time for 85% of the trips. Calculated as the standard deviation divided by the average travel rate.

An exhibit will be inserted here to illustrate annual trends once we have more than 1 year of data.

Exhibit D-2. Hampton Roads Regional Area
(Source: Virginia DOT and ITERIS)

<u>Routes included in performance measure estimates</u>:

I-264 (EB 6.3 mi, WB 6.3 mi)
I-64 (EB 11.4 mi, WB 11.4 mi, HOV 8.2 mi)
I-564 (EB 1.6 mi, WB 2.0 mi)

Where and When Delay Occurs

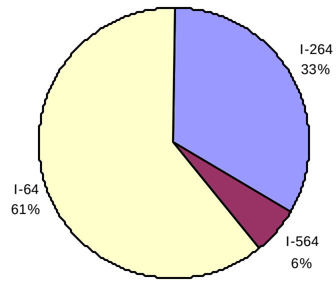


Exhibit D-3. Delay by Roadway

- Two-thirds of the delay occurs on I-64.
- I-564 is relatively short; corridor statistics show some intense congestion.

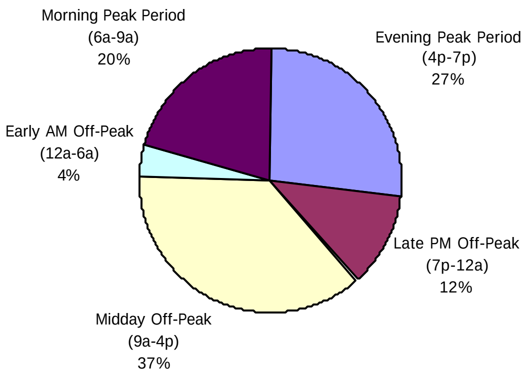


Exhibit D-4. Delay by Time of Day

- The midday off-peak period has more delay than either of the traditional peak periods.
- The 6 peak hours contain less than half of total delay.
- Port-related activities, as well as daytime speeds just below 60 mph may explain midday delay.

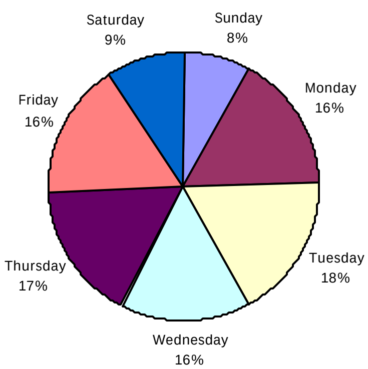
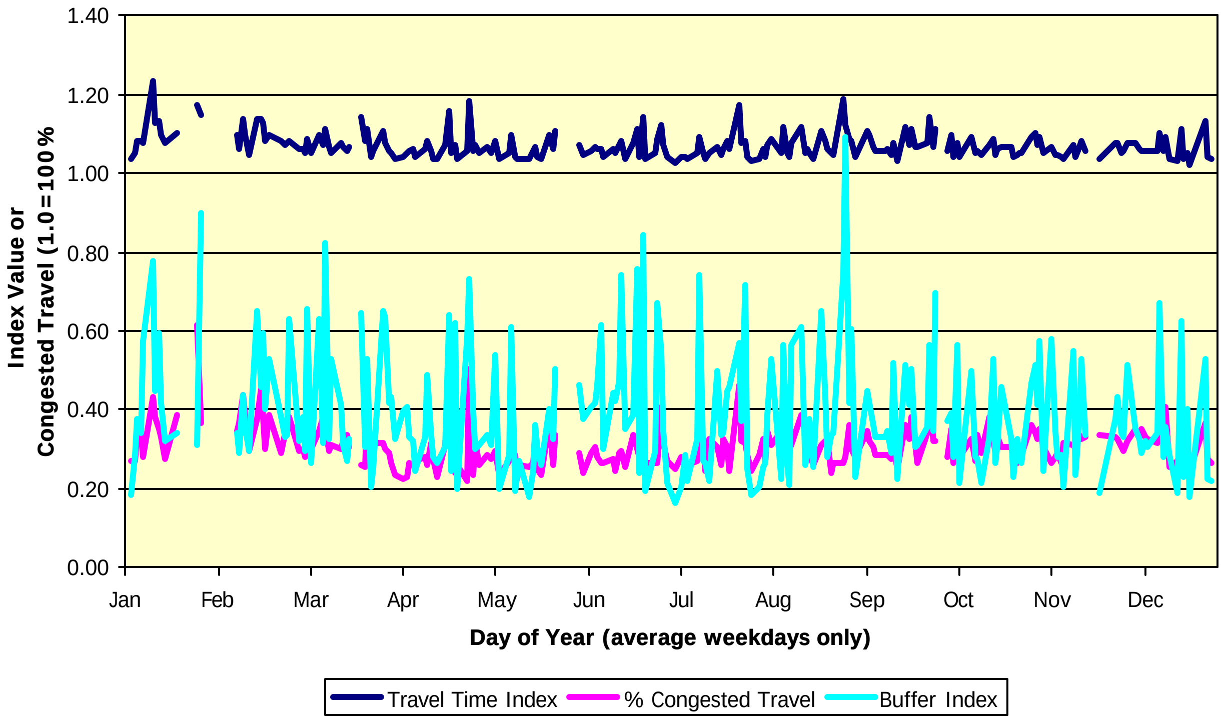


Exhibit D-5. Delay by Day of Week

- The weekend days combined have as much delay as a typical weekday.
- Tuesday and Thursday delays are slightly higher.



Note: Trend lines will be added to this graph when data from a sufficient time has been collected. Until multiple years of data are analyzed, the apparent trend may only be a seasonal variation in travel conditions.

Exhibit D-6. Mobility and Reliability Measures by Day of the Year

- There are several significantly unreliable days. These may be related to high travel demands associated with ship arrivals and departures.
- January and February saw some lapses in data availability.

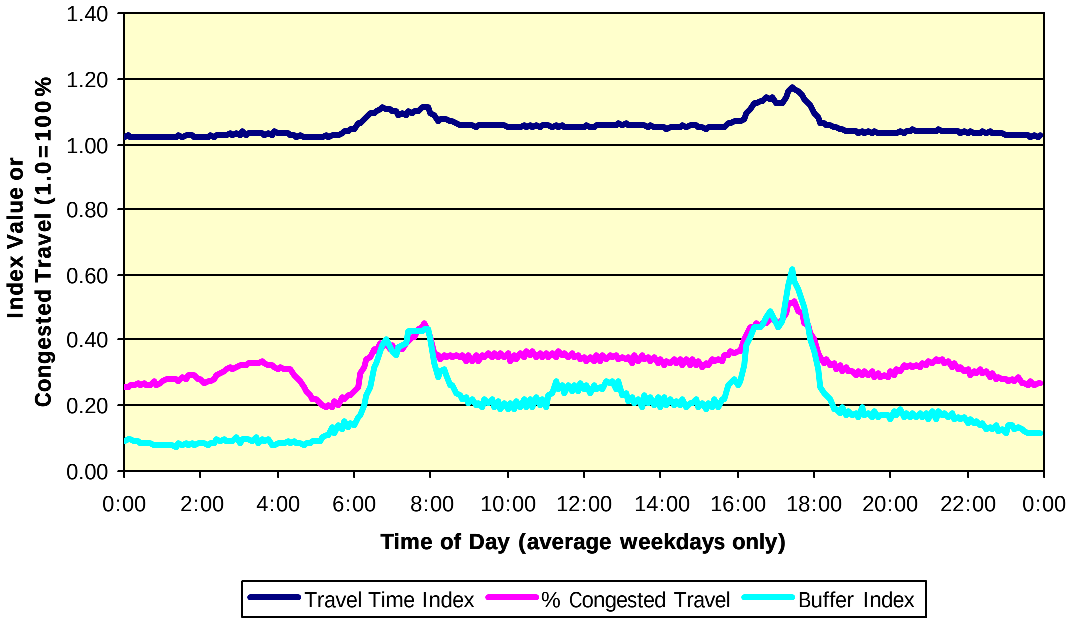


Exhibit D-7. Mobility and Reliability Measures by Time of an Average Day

- All three measures have the same trend. Congestion and unreliable conditions peak at the same time.
- The percent congested travel (slow speeds) are relatively high during the middle of the day, possibly due to low urban freeway speed limits.
- Percent congested travel declines as the morning peak approaches.

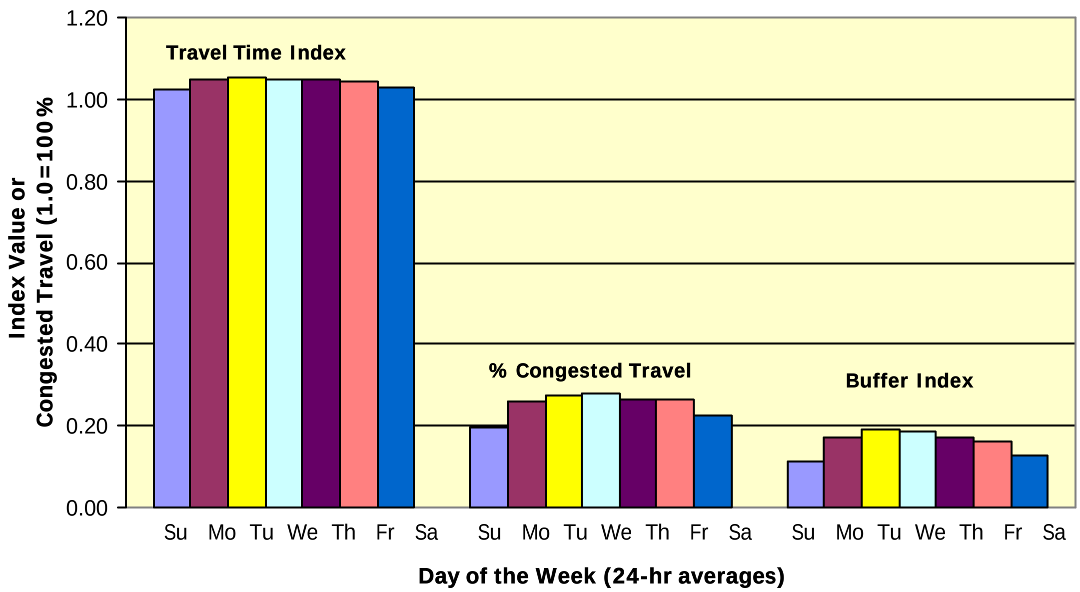


Exhibit D-8. Mobility and Reliability Measures by Day of an Average Week

- Unreliable travel and congestion peaks on Tuesdays, but not at significantly higher values than other weekdays.

2000 MOBILITY AND RELIABILITY REPORT—
BY DIRECTIONAL SECTION, HAMPTON ROADS, VIRGINIA

Exhibit D-9. Top Ten List—Most Congested Peak Periods

Rank	Directional Section	Date	Time Period	Travel Time Index
1	I-564 EB	October 23, 2000	AM Peak	4.35
2	I-564 WB	June 22, 2000	AM Peak	3.95
3	I-64 HOV	December 27, 2000	AM Peak	3.95
4	I-564 WB	July 24, 2000	AM Peak	3.17
5	I-564 WB	September 19, 2000	AM Peak	3.13
6	I-564 WB	January 25, 2000	Midday Off-Peak	3.06
7	I-564 WB	January 10, 2000	AM Peak	2.45
8	I-564 WB	September 6, 2000	AM Peak	2.87
9	I-564 EB	January 25, 2000	Midday Off-Peak	2.71
10	I-564 WB	January 18, 2000	AM Peak	2.47

Exhibit D-10. Top Ten List—Least Reliable Peak Periods

Rank	Directional Section	Date	Time Period	Buffer Index
1	I-64 EB	January 26, 2000	PM Peak Period	986%
2	I-564 WB	September 19, 2000	Late PM Off-Peak	938%
3	I-564 WB	July 11, 2000	AM Peak Period	764%
4	I-564 WB	September 20, 2000	Late PM Off-Peak	606%
5	I-564 EB	September 13, 2000	Late PM Off-Peak	476%
6	I-564 WB	September 20, 2000	Early AM Off-Peak	451%
7	I-64 WB	July 26, 2000	PM Peak Period	445%
8	I-264 WB	April 24, 2000	AM Peak Period	421%
9	I-64 WB	March 28, 2000	AM Peak Period	406%
10	I-64 EB	December 19, 2000	AM Peak Period	351%

- I-564 has several very congested and unreliable peaks. The freeway connects to the Norfolk Naval Base (WB is towards the Base).
- Local officials indicate midday and early morning congestion and unreliability is often related to ship arrivals and departures.
- June 22, January 10/11, September 18/19/20 and September 5/6 are particularly bad for both congestion and reliability.
- I-564 EB is usually uncongested at all times but has some of the most congested and least reliable periods.

Exhibit D-11. Travel Time Index—Hampton Roads Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL							
I-264 EB (I-64/I-664 to Downtown Tunnel, 6.3 mi)	1.05	1.05	1.04	1.12	1.08	1.04	1.06
I-264 WB (Downtown Tunnel to I-64/I-664, 6.3 mi)	1.08	1.06	1.05	1.09	1.06	1.05	1.06
CENTRAL-SUBURBAN							
I-64 EB (I-564 to Chesapeake City Line, 11.4 mi)	1.05	1.04	1.04	1.22	1.14	1.06	1.09
I-64 WB (Chesapeake City Line to I-564, 11.4 mi)	1.20	1.14	1.08	1.14	1.11	1.09	1.12
I-64 HOV (I-564 to I-264, 8.2 mi)	1.12	1.03	1.02	1.02	1.02	1.02	1.03
SUBURBAN							
I-564 EB (Naval Station to I-64, 1.60 mi)	1.02	1.01	1.00	1.00	1.00	1.00	1.00
I-564 WB (I-64 to Naval Station, 2.00 mi)	1.25	1.22	1.14	1.20	1.13	1.15	1.18
CORRIDOR AVERAGE	**1.09**	**1.06**	**1.04**	**1.11**	**1.07**	**1.05**	**1.07**

Note: These performance measures represent the portion (19.7 miles) of the total freeway system (159 miles) that contains ITS traffic monitoring sensors.

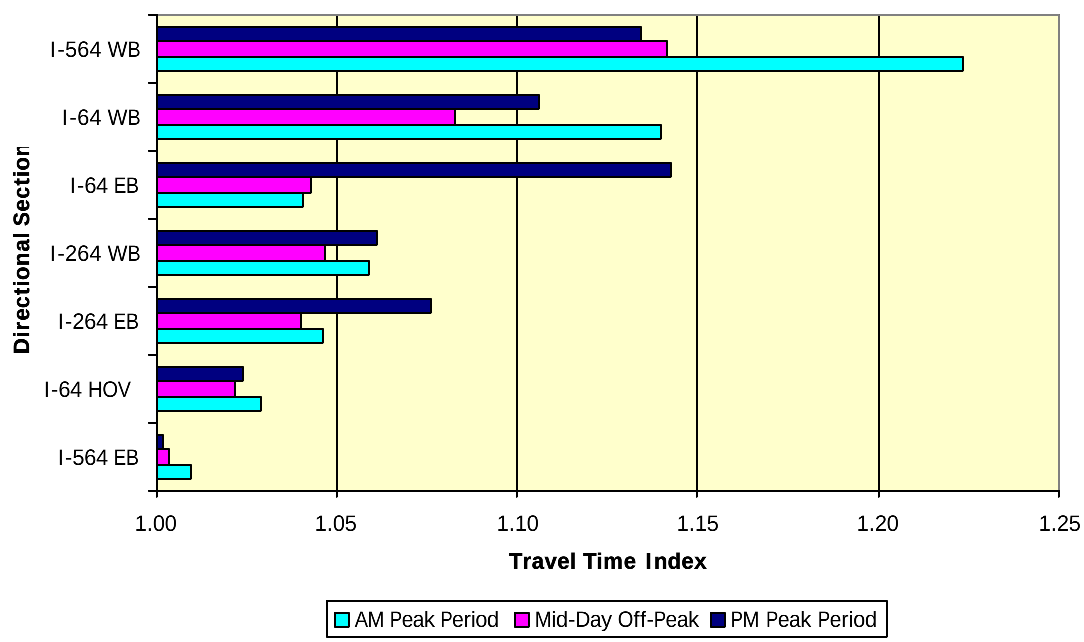


Exhibit D-12. Travel Time Index, by Directional Section

- I-564 WB is more congested than EB for all peaks. This may be the effect of the exits from the Naval Base metering traffic.
- I-564 WB has the most congested periods, including a midday TTI that exceeds the average peaks of the other freeways.
- Congestion levels on Hampton Roads freeways are not high relative to other cities.

Exhibit D-13. Buffer Index—Hampton Roads Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL							
I-264 EB (I-64/I-664 to Downtown Tunnel, 6.3 mi)	11%	11%	11%	71%	36%	10%	26%
I-264 WB (Downtown Tunnel to I-64/I-664, 6.3 mi)	51%	49%	52%	53%	50%	40%	49%
CENTRAL-SUBURBAN							
I-64 EB (I-564 to Chesapeake City Line, 11.4 mi)	12%	12%	14%	72%	57%	12%	37%
I-64 WB (Chesapeake City Line to I-564, 11.4 mi)	73%	52%	19%	39%	25%	17%	39%
I-64 HOV (I-564 to I-264, 8.2 mi)	1%	1%	5%	7%	6%	5%	3%
SUBURBAN							
I-564 EB (Naval Station to I-64, 1.6 mi)	1%	2%	0%	0%	1%	1%	2%
I-564 WB (I-64 to Naval Station, 2.0 mi)	63%	62%	68%	40%	42%	53%	55%
CORRIDOR AVERAGE	**38%**	**31%**	**21%**	**57%**	**40%**	**18%**	**30%**

Note: These performance measures represent the portion (19.7 miles) of the total freeway system (159 miles) that contains ITS traffic monitoring sensors.

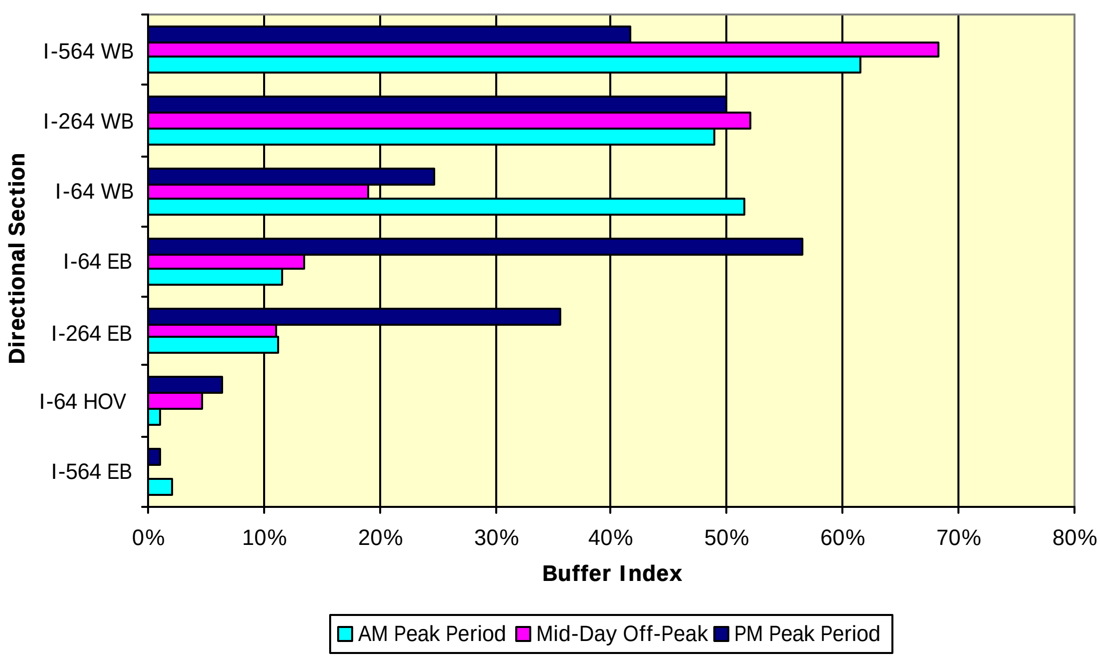


Exhibit D-14. Buffer Index, by Directional Section

- Midday travel conditions are not much more reliable than a peak period in many corridors.
- Westbound travel is less reliable than eastbound.
- The largest difference in reliability between periods is on I-64 EB.
- The I-64 HOV lane and I-564 EB are noticeably more reliable than the other freeways.

Appendix E—Houston, TX

2000 Regional Mobility and Reliability Data

A Supplement to:

Monitoring Urban Roadways: Using Archived Operations Data for Reliability and Mobility Measurement by Texas Transportation Institute and Cambridge Systematics, Inc., May 2001

Houston, TX Findings

- The evening peak has almost half of the measured delay.
- More than 40% of delay is over two congested freeways—I-10 West Katy and I-610 West Loop.
- September to December is the least reliable travel period.
- Congested travel percentage is relatively low through the year.
- Evening peak congestion and reliability problems are more severe and last longer than the morning.
- Reliability problems grow through the week with Friday being much worse than Monday.
- Suburban congestion is relatively low.
- Toll highways and HOV lanes have very low congestion.

Houston, TX Data Source

- Approximately 225 miles of the 400-mile freeway system is included in the archived data system. The data was provided by Texas DOT and TTI's Houston office.
- Travel time data was collected by region-wide AVI system. Travel times were measured directly; 5-minute vehicle volumes were estimated from ADT. Travel time data was reported at the individual vehicle level (vehicle identification numbers were anonymous).
- 99% of the volume and 95% of the speed data in the original data archive passed the initial quality control tests.
- The original data included data for 75% of the volume and 56% of the speed records for 2000.
- After removing data that failed the quality control checks and identifying missing data, between 15% and 20% of the possible speed and volume records from the detector system were found to be usable for further analysis. Fortunately, 92% of the time periods had usable data from the AVI system, and volume estimates were used.

Major Study Findings (Why you should read the Final Report)

- It is only 36 pages.
- Local data archiving occurs in some areas but easy accessibility and use of that data is much less widespread. Database management and analytical methods can be somewhat complex, and limited local resources and guidance have also hindered widespread development of easy-to-use data archives. Each area has essentially pursued their own development schedule and scope with funding from local sources. The report, and the associated best practices guide can assist agencies in the data archiving process.
- The mobility and reliability measures used in the report can most efficiently be used for local area trend analysis and analysis of important subjects at the national level. The data are less useful for city-to-city comparisons because of the incomplete ITS coverage and inconsistencies between cities. The report summarizes the measures used in the study and demonstrates how they can be prepared and interpreted.

Exhibit E-1. Trends in Mobility and Reliability Indicators

Indicator	2000	1999	Change
MOBILITY			
Travel Time Index	1.26		
Delay per Capita (hours)	4.8		
Percent Congested Travel	25%		
RELIABILITY			
Buffer Index	50%		
Misery Rate	28%		
Percent Variation	32%		

Notes: [1]These performance measures represent the portion (225 miles) of the total freeway system (400 miles) that contains ITS traffic monitoring sensors.
[2]All statistics reported in this exhibit are peak period averages for all weekdays in the year indicated (no holidays included).
[3]This exhibit will be used to illustrate annual trends once we have more than one year of data.

- The relatively low Houston travel rate index can be partially explained by the inclusion of HOV facilities and the high-volume, high-speed travel in the off-peak direction and off-peak periods of several freeways.

Data analysis by Texas Transportation Institute and Cambridge Systematics, Inc.
Data provided by Texas DOT and TTI-Houston.

Travel Time Index—A ratio of peak travel rate to a free-flow travel rate. A TTI of 1.3 indicates a 20-minute off-peak trip would take 26 minutes in the peak.
Delay per Capita—Estimate of the annual delay (in hours) per person in the urban area. Until a larger percentage of the system is instrumented, this value will be artificially low.
Percent Congested Travel—The percentage of vehicle-miles of travel that occur below 60 mph.
Buffer Index—The percentage of time above the average necessary to allow travelers to arrive on time for 95% of trips. The difference between the 95th and average travel rate divided by the average travel rate.
Misery Rate—The length of delay for the most congested 20% of the trips. The average travel rate is subtracted from the average rate for the slowest 20% of the trips. The Misery Rate is a percentage of extra time needed for the worst 20% of the trips.
Percent Variation—The amount of extra time needed to be on time for 85% of the trips. Calculated as the standard deviation divided by the average travel rate.

An exhibit will be inserted here to illustrate annual trends once we have more than 1 year of data.

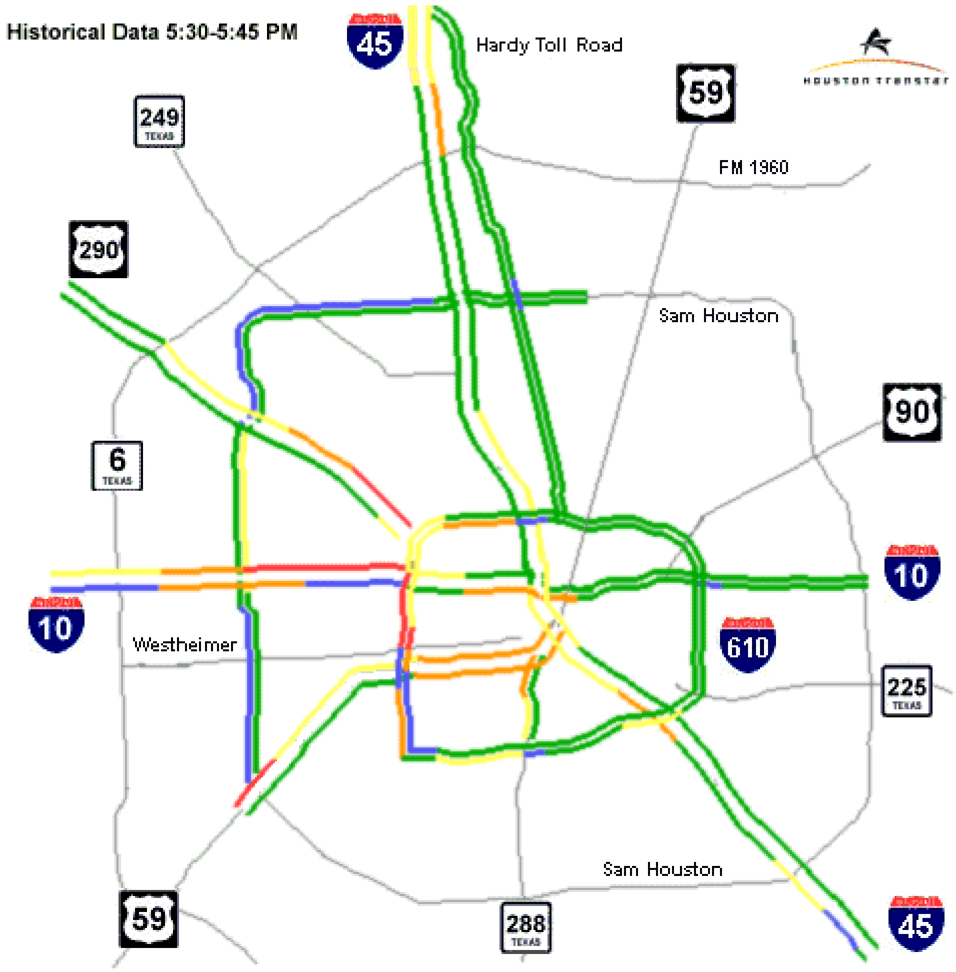


Exhibit E-2. Houston, Texas Regional Area
(Source: Texas DOT's TranStar, http://traffic.tamu.edu)

Routes included in performance measure estimates:
I-10 East (EB 12.50 mi, WB 12.50 mi)
I-10 Katy (EB 19.95 mi, WB 19.95 mi, HOV 10.05 mi)
I-45 Gulf (NB 21.60 mi, SB 21.7 mi, HOV 11.80 mi)
I-45 North (NB 23.10 mi, SB 25.42 mi, 11.55 mi)
I-610 West Loop (NB 8.90 mi, SB 9.61 mi)
I-610 East Loop (NB 10.10 mi, SB 10.30 mi)
I-610 North Loop (EB 9.30 mi, WB 9.40 mi)
I-610 South Loop (EB 9.20 mi, WB 9.70 mi)
US 59 Eastex (NB 19.55 mi, SB 19.55 mi)
US 59 Southwest (EB 15.71 mi, WB 15.71 mi, HOV 8.05 mi)
US 290 Northwest (EB 17.15 mi, WB 17.15 mi, HOV 12.35 mi)
Hardy Toll Road (NB 21.25 mi, SB 21.15 mi)
Sam Houston Parkway (CW 8.05 mi, CCW 17.60 mi)
Sam Houston Tollway (CW 12.35 mi, CCW 14.85 mi)
SH 288 South (NB 3.30 mi, SB 3.37 mi)

Where and When Delay Occurs

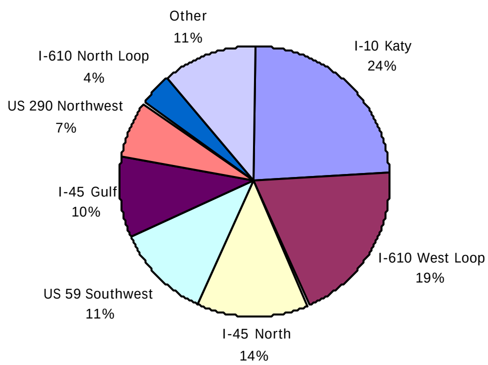


Exhibit E-3. Delay by Roadway

- The Southwest, North and Katy Freeways have almost half of total delay.
- I-610 West Loop has the second most delay, despite being one of the shortest corridors.

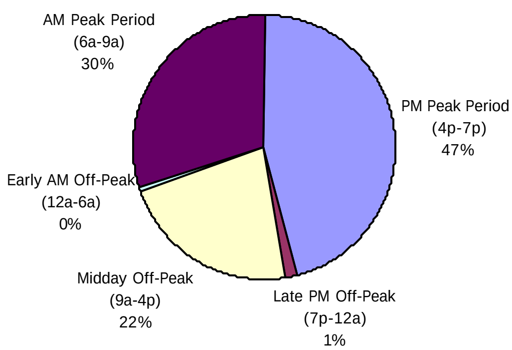


Exhibit E-4. Delay by Time of Day

- The evening peak has almost half of the measured delay.
- Midday off-peak congestion is a significant issue; not as intense, but with delay close to the morning peak.
- Late night and early morning delay is not a problem.

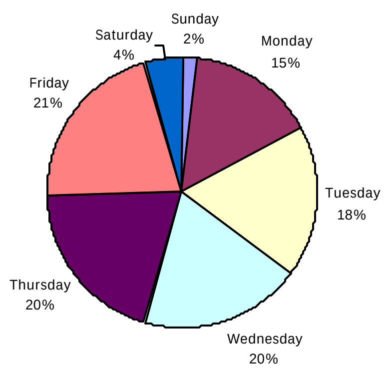
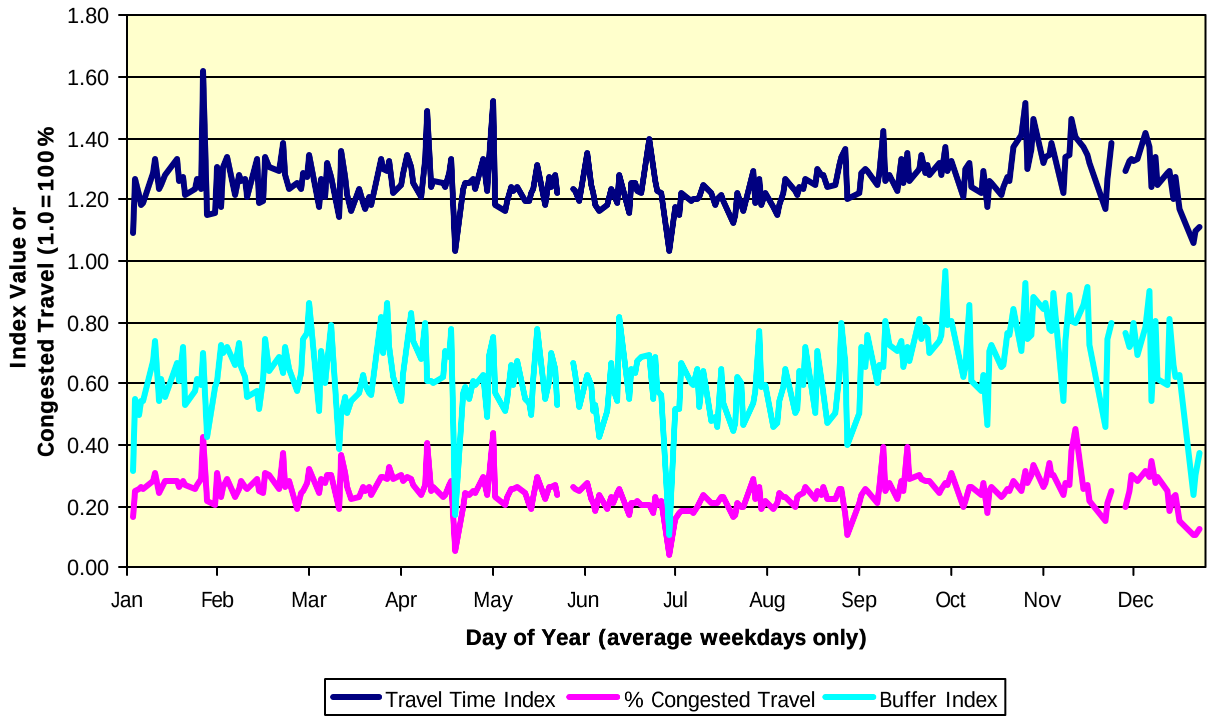


Exhibit E-5. Delay by Day of Week

- Weekend day delay is very low.
- Congestion levels are remarkably similar from Tuesday to Friday.



Note: Trend lines will be added to this graph when data from a sufficient time has been collected. Until multiple years of data are analyzed, the apparent trend may only be a seasonal variation in travel conditions.

Exhibit E-6. Mobility and Reliability Measures by Day of the Year

- While congestion patterns are relatively consistent, reliability levels vary significantly.
- The fall appears to be relatively less reliable—this may be a seasonal effect or an increasing trend.
- Congested travel remains relatively low.

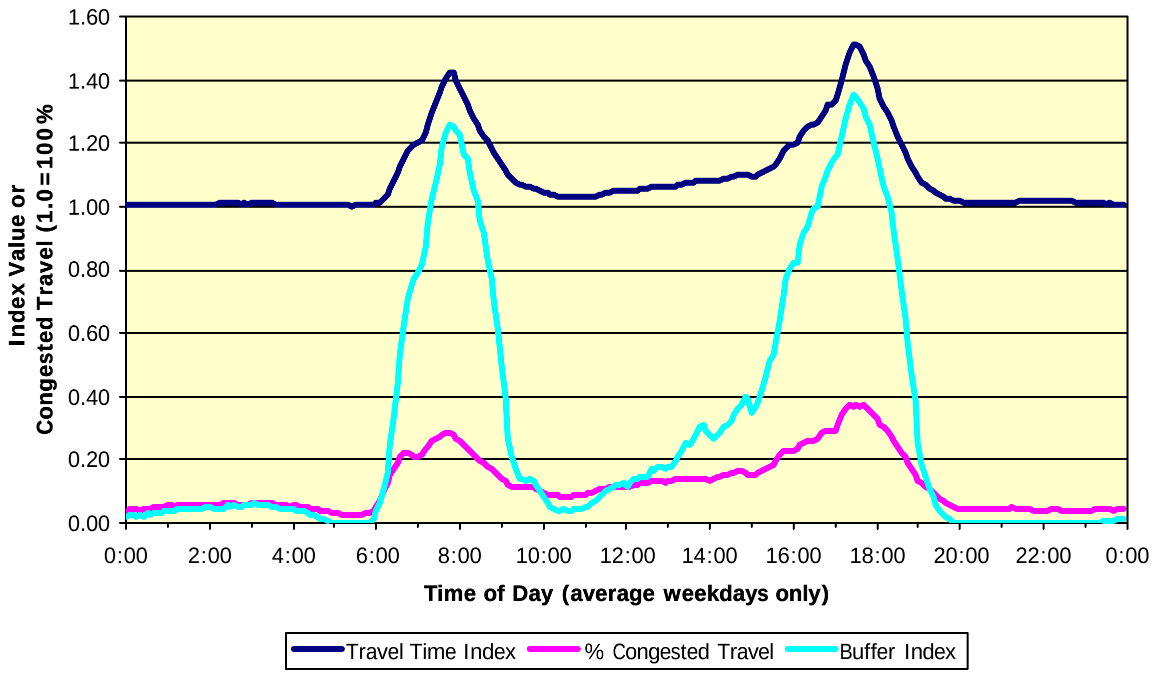


Exhibit E-7. Mobility and Reliability Measures by Time of an Average Day

- High-speed operation in the off-peaks is presented as a TTI of 1.0.
- The evening peak period has more congestion and lasts for longer time than the morning.
- Reliability problems are much greater during the peak periods.
- The off-peaks show the effect of the research team's decision to not allow the TTI to be less than 1.0.

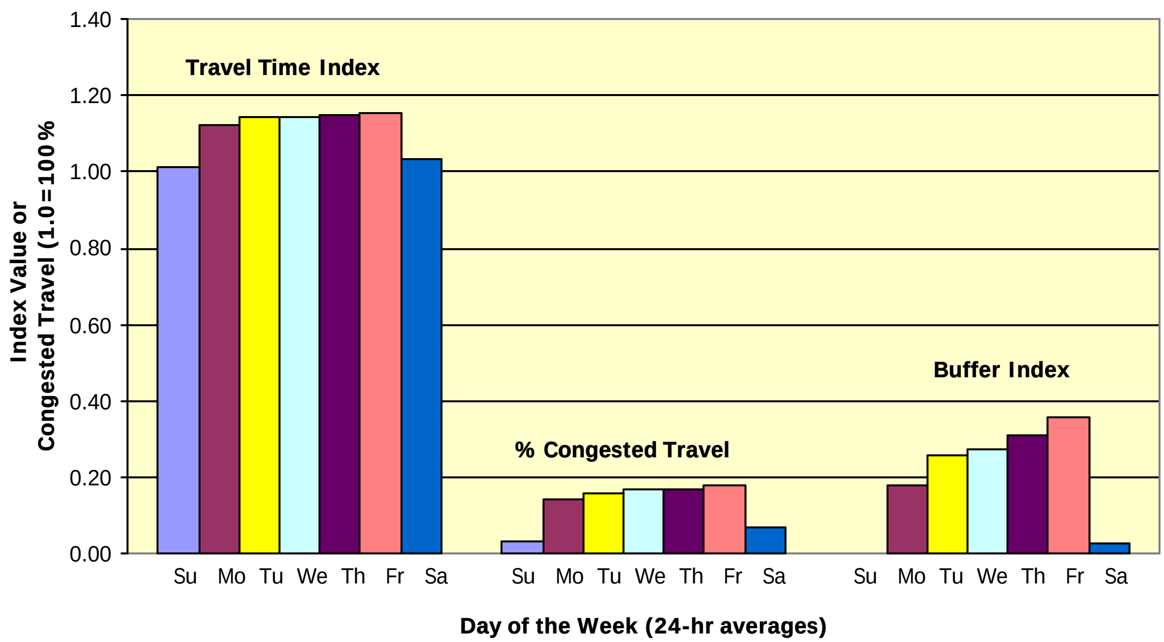


Exhibit E-8. Mobility and Reliability Measures by Day of an Average Week

- Weekend days are more reliable than weekdays, but not without problems.
- Reliability problems grow through the week, with Friday being much worse than Monday.

Exhibit E-9. Top Ten List—Most Congested Peak Periods

Rank	Directional Section	Date	Time Period	Travel Time Index
1	I-610 East Loop NB	June 21, 2000	PM Peak Period	6.26
2	I-610 West Loop NB	June 26, 2000	PM Peak Period	5.87
3	I-10 East WB	October 30, 2000	AM Peak Period	5.34
4	I-610 West Loop NB	May 4, 2000	PM Peak Period	5.20
5	US 59 Southwest EB	January 27, 2000	PM Peak Period	4.69
6	I-610 East Loop NB	November 20, 2000	PM Peak Period	4.39
7	US 59 Southwest WB	November 22, 2000	PM Peak Period	4.33
8	I-610 West Loop NB	October 31, 2000	PM Peak Period	4.29
9	US 290 Northwest EB	November 16, 2000	AM Peak Period	4.27
10	I-610 West Loop NB	May 3, 2000	PM Peak Period	4.12

Exhibit E-10. Top Ten List—Least Reliable Peak Periods

Rank	Directional Section	Date	Time Period	Buffer Index
1	I-45 North NB	October 12, 2000	Late PM Off-Peak	709%
2	US 59 Southwest EB	February 2, 2000	AM Peak Period	642%
3	Sam Houston Tollway WB	April 11, 2000	AM Peak Period	564%
4	US 59 Southwest WB	December 12, 2000	AM Peak Period	559%
5	US 290 Northwest WB	November 20, 2000	AM Peak Period	552%
6	US 59 Southwest EB	June 2, 2000	AM Peak Period	548%
7	US 59 Southwest WB	June 16, 2000	AM Peak Period	530%
8	US 59 Southwest EB	December 4, 2000	AM Peak Period	518%
9	I-610 West Loop NB	October 27, 2000	Late PM Off-Peak	508%
10	I-610 West Loop NB	June 1, 2000	Late PM Off-Peak	498%

- The Loop corridors are a significant part of both lists.
- There is no agreement between the two lists—the dates and corridors with the most severe problems are different.
- Most of the periods on the lists are peak periods.
- The Buffer Index values are some of the highest in the study.

Exhibit E-11. Travel Time Index—Houston Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL-SUBURBAN							
I-10 Katy, EB (Barker Cypress to Smith, 19.95 mi)	1.92	1.65	1.18	1.64	1.46	1.32	1.55
I-10 Katy, WB (I-45 to Barker Cypress, 19.95 mi)	1.12	1.11	1.17	2.27	1.91	1.29	1.51
I-45 Gulf, NB (NASA Rd 1 to Allen Pkwy, 21.60 mi)	1.74	1.46	1.07	1.13	1.11	1.16	1.29
I-45 Gulf, SB (Allen Pkwy to NASA Rd 1, 21.7 mi)	1.01	1.02	1.03	1.38	1.25	1.07	1.13
I-45 North, NB (I-10 to Hardy Toll Rd, 23.10 mi)	1.05	1.05	1.07	1.40	1.30	1.11	1.17
I-45 North, SB (Hardy Toll Rd to Allen Pkwy, 25.42 mi)	1.56	1.38	1.09	1.26	1.21	1.17	1.30
I-610 West Loop, NB (Evergreen to Ella Blvd, 8.90 mi)	1.23	1.16	1.29	2.35	2.07	1.40	1.62
I-610 West Loop, SB (Ella Blvd to S. Post Oak, 9.61 mi)	1.55	1.46	1.33	2.60	2.10	1.48	1.78
US 59 Southwest, EB (Wilcrest to I-45 Gulf, 15.71 mi)	1.62	1.38	1.06	1.24	1.19	1.15	1.29
US 59 Southwest ,WB (I-45 Gulf to Wilcrest, 15.71 mi)	1.18	1.16	1.06	1.79	1.56	1.19	1.36
I-10 Katy, EB HOV (SH 6 to Silber, 10.05 mi)	1.02	1.02	1.00			1.01	1.02
I-10 Katy, WB HOV (Silber to SH 6, 10.05 mi)			1.00	1.04	1.03	1.01	1.03
I-45 Gulf, NB HOV (Fuqua to Scott St, 11.80 mi)	1.15	1.11	1.03			1.06	1.11
I-45 Gulf, SB HOV (Scott St to Fuqua, 11.80 mi)			1.04	1.10	1.07	1.05	1.07
I-45 North, NB HOV (I-10 to Aldine Bender, 11.55 mi)			1.01	1.07	1.05	1.02	1.05
I-45 North, SB HOV (Aldine Bender to I-10, 11.55 mi)	1.24	1.12	1.01			1.05	1.12
US 290 Northwest, EB HOV (West Rd to Old Katy Rd, 12.35 mi)	1.05	1.06	1.03			1.04	1.06
US 290 Northwest, WB HOV (Old Katy Rd to West Rd, 12.35 mi)			1.02	1.07	1.05	1.03	1.05
US 59 Southwest, EB HOV (Bissonnet to Newcastle, 8.05 mi)	1.19	1.16	1.09			1.12	1.16
US 59 Southwest, WB HOV (Newcastle to Bissonnet, 8.05 mi)			1.10	1.21	1.17	1.12	1.17

Exhibit E-11. Continued

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
SUBURBAN							
Hardy Toll Road, NB (I-610 to I-45, 21.15 mi)	1.00	1.00	1.00	1.06	1.03	1.01	1.02
Hardy Toll Road, SB (I-45 to I-610, 21.15 mi)	1.01	1.01	1.00	1.00	1.00	1.00	1.00
I-10 East, EB (Smith to Beltway 8, 12.50 mi)	1.01	1.01	1.01	1.17	1.10	1.03	1.05
I-10 East, WB (Beltway 8 to I-45, 12.50 mi)	1.73	1.41	1.02	1.01	1.01	1.10	1.21
I-610 East Loop, NB (S. Wayside to N. Wayside, 10.10 mi)	1.02	1.01	1.02	1.20	1.14	1.05	1.08
I-610 East Loop, SB (N. Wayside to S. Wayside, 10.30 mi)	1.13	1.08	1.02	1.05	1.03	1.04	1.06
I-610 North Loop, EB (Ella Blvd to N. Wayside, 9.30 mi)	1.03	1.02	1.05	1.72	1.47	1.13	1.24
I-610 North Loop, WB (Lockwood to Ella Blvd, 9.40 mi)	1.62	1.43	1.05	1.07	1.05	1.13	1.24
I-610 South Loop, EB S. Post Oak to S. Wayside, 9.20 mi)	1.02	1.01	1.01	1.26	1.14	1.04	1.07
I-610 South Loop, WB (S. Wayside to Evergreen, 9.70 mi)	1.29	1.17	1.01	1.04	1.02	1.05	1.09
N. Sam Houston Parkway, WB (Ella Blvd to I-10, 17.60 mi)	1.11	1.09	1.02	1.07	1.05	1.04	1.07
Sam Houston Tollway, NB (Ella Blvd to Memorial Dr, 12.35 mi)	1.08	1.05	1.01	1.10	1.06	1.03	1.06
Sam Houston Tollway, WB (JFK Blvd to US 59 SW, 14.85 mi)	1.02	1.01	1.00	1.14	1.07	1.02	1.04
SH 288 South, NB (Holly Hall to US 59, 3.30 mi)	1.29	1.15	1.01	1.03	1.02	1.04	1.08
SH 288 South, SB (US 59 to Holly Hall, 3.37 mi)	1.01	1.01	1.01	1.75	1.32	1.08	1.16
US 290 Northwest, EB (Barker Cypress to Dacoma, 17.15 mi)	2.04	1.67	1.04	1.06	1.03	1.17	1.35
US 290 Northwest, WB (Dacoma to Barker Cypress, 17.15 mi)	1.01	1.01	1.04	2.11	1.73	1.18	1.37
US 59 Eastex, NB (I-45 Gulf to Townsen, 19.55 mi)	1.02	1.02	1.03	1.36	1.25	1.07	1.14
US 59 Eastex, SB (Townsen to I-45 Gulf, 19.55 mi)	1.64	1.65	1.06	1.06	1.08	1.18	1.35
W. Sam Houston Parkway, NB (Memorial Dr to Ella Blvd, 8.05 mi)	1.03	1.02	1.02	1.20	1.12	1.04	1.07
CORRIDOR AVERAGE	**1.32**	**1.22**	**1.07**	**1.42**	**1.30**	**1.14**	**1.26**

Note: These performance measures represent the portion (225 miles) of the total freeway system (400 miles) that contains ITS traffic monitoring sensors.

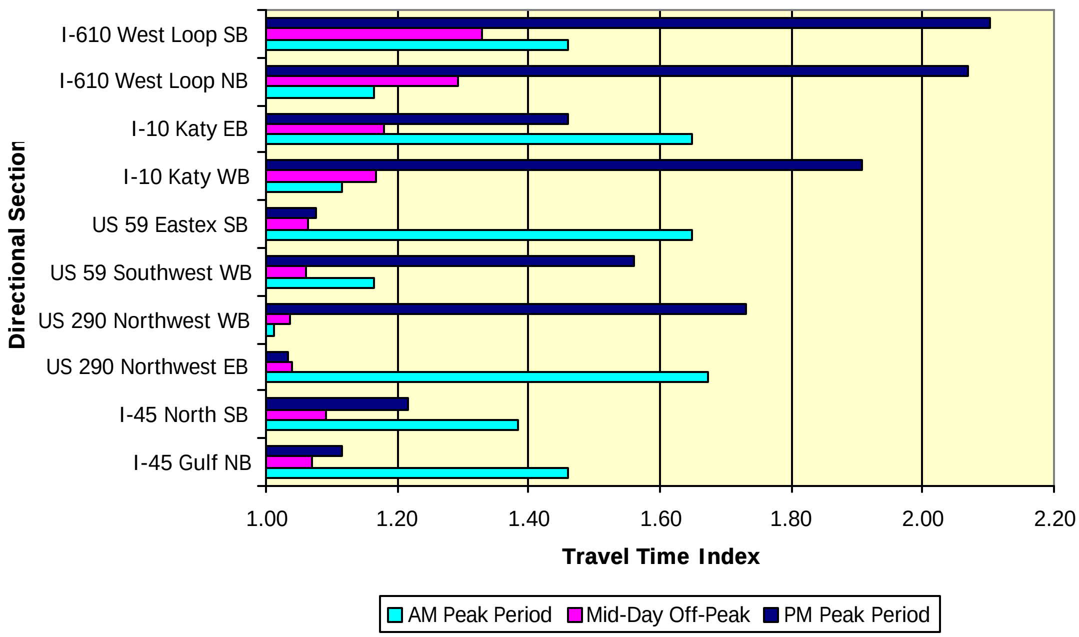


Exhibit E-12. Travel Time Index, by Ten Most Congested Directional Sections

- The lack of congestion and high volume in the Suburban corridors and on the toll highways, as well as the inclusion of the HOV corridors, brings the average TRI value down.
- Evening peak congestion is typically more intense.
- The West Loop and Katy Freeways have the most congested corridors.
- Very few corridors exhibit a double peak—very congested corridors in the morning and evening.
- HOV corridors are reversible—only one peak period operates in each direction.

Exhibit E-13. Buffer Index—Houston Annual Summary, Year 2000

Corridor	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL-SUBURBAN							
I-10 Katy, EB (Barker Cypress to Smith, 19.95 mi)	132%	132%	64%	132%	128%	73%	130%
I-10 Katy, WB (I-45 to Barker Cypress, 19.95 mi)	48%	54%	58%	99%	104%	61%	79%
I-45 Gulf, NB (NASA Rd 1 to Allen Pkwy, 21.60 mi)	97%	98%	14%	49%	40%	28%	69%
I-45 Gulf, SB (Allen Pkwy to NASA Rd 1, 21.7 mi)	4%	4%	10%	106%	100%	13%	52%
I-45 North, NB (I-10 to Hardy Toll Rd, 23.10 mi)	60%	64%	75%	90%	89%	58%	77%
I-45 North, SB (Hardy Toll Rd to Allen Pkwy, 25.42 mi)	94%	98%	65%	114%	108%	66%	103%
I-610 West Loop, NB (Evergreen to Ella Blvd, 8.90 mi)	92%	89%	146%	135%	144%	129%	117%
I-610 West Loop, SB (Ella Blvd to S. Post Oak, 9.61 mi)	100%	110%	101%	82%	97%	101%	103%
US 59 Southwest, EB (Wilcrest to I-45 Gulf, 15.71 mi)	113%	123%	26%	174%	151%	39%	137%
US 59 Southwest, WB (I-45 Gulf to Wilcrest, 15.71 mi)	180%	174%	24%	195%	210%	66%	192%
I-10 Katy, EB HOV (SH 6 to Silber, 10.05 mi)	6%	9%	1%			7%	9%
I-10 Katy, WB HOV (Silber to SH 6, 10.05 mi)			2%	9%	9%	6%	9%
I-45 Gulf, NB HOV (Fuqua to Scott St, 11.80 mi)	25%	21%	14%			20%	21%
I-45 Gulf, SB HOV (Scott St to Fuqua, 11.80 mi)			14%	16%	16%	15%	16%
I-45 North, NB HOV (I-10 to Aldine Bender, 11.55 mi)			7%	15%	14%	11%	14%
I-45 North, SB HOV (Aldine Bender to I-10, 11.55 mi)	52%	42%	6%			32%	42%
US 290 Northwest, EB HOV (West Rd to Old Katy Rd, 12.35 mi)	18%	17%	13%			17%	17%
US 290 Northwest, WB HOV (Old Katy Rd to West Rd, 12.35 mi)			11%	14%	13%	12%	13%
US 59 Southwest, EB HOV (Bissonnet to Newcastle, 8.05 mi)	13%	15%	16%			15%	15%
US 59 Southwest, WB HOV (Newcastle to Bissonnet, 8.05 mi)			16%	15%	14%	15%	14%

Exhibit E-13. Continued

Corridor	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
SUBURBAN							
Hardy Toll Road, NB (I-610 to I-45, 21.15 mi)	0%	0%	0%	27%	11%	1%	6%
Hardy Toll Road, SB (I-45 to I-610, 21.15 mi)	1%	1%	0%	0%	0%	0%	0%
I-10 East, EB (Smith to Beltway 8, 12.50 mi)	1%	0%	1%	108%	92%	4%	46%
I-10 East, WB (Beltway 8 to I-45, 12.50 mi)	142%	141%	0%	0%	1%	3%	70%
I-610 East Loop, NB (S. Wayside to N. Wayside, 10.10 mi)	2%	1%	1%	59%	39%	1%	19%
I-610 East Loop, SB (N. Wayside to S. Wayside, 10.30 mi)	58%	43%	4%	17%	10%	8%	26%
I-610 North Loop, EB (Ella Blvd to N. Wayside, 9.30 mi)	4%	0%	3%	71%	74%	-1%	37%
I-610 North Loop, WB (Lockwood to Ella Blvd, 9.40 mi)	126%	117%	12%	16%	15%	16%	66%
I-610 South Loop, EB (S. Post Oak to S. Wayside, 9.20 mi)	4%	1%	1%	93%	65%	2%	33%
I-610 South Loop, WB (S. Wayside to Evergreen, 9.70 mi)	70%	62%	1%	9%	3%	2%	32%
N. Sam Houston Parkway, WB (Ella Blvd to I-10, 17.60 mi)	34%	37%	0%	25%	22%	9%	30%
Sam Houston Tollway, NB (Ella Blvd to Memorial Dr, 12.35 mi)	61%	28%	1%	33%	14%	2%	21%
Sam Houston Tollway, WB (JFK Blvd to US 59 SW, 14.85 mi)	3%	0%	0%	43%	28%	2%	14%
SH 288 South, NB (Holly Hall to US 59, 3.30 mi)	62%	59%	2%	6%	4%	8%	32%
SH 288 South, SB (US 59 to Holly Hall, 3.37 mi)	3%	2%	1%	73%	90%	6%	46%
US 290 Northwest, EB (Barker Cypress to Dacoma, 17.15 mi)	147%	168%	0%	22%	0%	81%	84%
US 290 Northwest, WB (Dacoma to Barker Cypress, 17.15 mi)	1%	1%	5%	103%	115%	52%	57%
US 59 Eastex, NB (I-45 Gulf to Townsen, 19.55 mi)	3%	3%	10%	85%	83%	24%	43%
US 59 Eastex, SB (Townsen to I-45 Gulf, 19.55 mi)	140%	147%	23%	32%	27%	49%	87%
W. Sam Houston Parkway, NB (Memorial Dr to Ella Blvd, 8.05 mi)	16%	12%	1%	42%	42%	11%	27%
CORRIDOR AVERAGE	**70%**	**71%**	**28%**	**83%**	**79%**	**38%**	**50%**

Note: These performance measures represent the portion (225 miles) of the total freeway system (400 miles) that contains ITS traffic monitoring sensors.

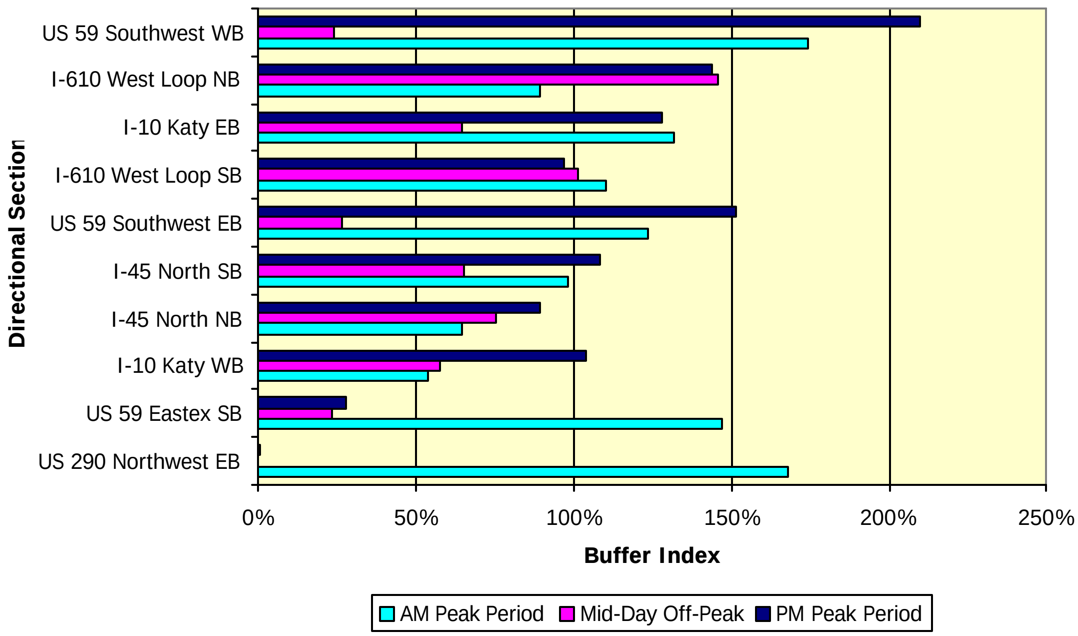


Exhibit E-14. Buffer Index, by Ten Least Reliable Directional Sections

- The HOV lanes, Hardy Toll Road and Sam Houston Tollway/Parkway are significantly more reliable than other corridors, showing the impact of premium services; occupancy restrictions and pricing have an effect.
- The most congested sections are also among the least reliable, especially in the midday.
- Southwest Freeway reliability problems can be partially explained by high-speed operations on some days, and by the varying influence of West Loop, which intersects the Southwest Freeway.
- Most non-HOV or toll road corridors have at least one period with a buffer index greater than 100%.

Appendix F—Los Angeles, CA

2000 Regional Mobility and Reliability Data

A Supplement to:

Monitoring Urban Roadways: Using Archived Operations Data for Reliability and Mobility Measurement by Texas Transportation Institute and Cambridge Systematics, Inc., May 2001

Los Angeles, CA Findings

- The morning and evening peak periods include only half of the total delay.
- Weekend delay is relatively low.
- Morning peak congestion is worse but the evening peak lasts longer.
- Buffer Index values are among the highest in the study.

Los Angeles, CA Data Source

- Approximately 329 miles of the more than 640-mile freeway system was included in this archived data analysis. The data was provided by Caltrans and data processing and analysis was performed by the University of California at Berkeley.
- The data was collected primarily using single inductive loops. Travel times and speeds were estimated by University of California-Berkeley. The data were reported by directional facility at 5-minute intervals.

Major Study Findings (Why you should read the Final Report)

- It is only 36 pages.
- Local data archiving occurs in some areas but easy accessibility and use of that data is much less widespread. Database management and analytical methods can be somewhat complex, and limited local resources and guidance have also hindered widespread development of easy-to-use data archives. Each area has essentially pursued their own development schedule and scope with funding from local sources. The report, and the associated best practices guide can assist agencies in the data archiving process.
- The mobility and reliability measures used in the report can most efficiently be used for local area trend analysis and analysis of important subjects at the national level. The data are less useful for city-to-city comparisons because of the incomplete ITS coverage and inconsistencies between cities. The report summarizes the measures used in the study and demonstrates how they can be prepared and interpreted.

Exhibit F-1. Trends in Mobility and Reliability Indicators

Indicator	2000	1999	Change
MOBILITY			
Travel Time Index	1.33		
Delay per Capita (hours)	4.4		
Percent Congested Travel	41%		
RELIABILITY			
Buffer Index	46%		
Misery Rate	49%		
Percent Variation	26%		

Notes: [1]These performance measures represent the portion (329.3 miles) of the total freeway system (641 miles) that contains ITS traffic monitoring sensors.

[2]All statistics reported in this exhibit are peak period averages for all weekdays in the year indicated (no holidays included).

[3]This exhibit will be used to illustrate annual trends once we have more than one year of data.

Data analysis by Texas Transportation Institute and Cambridge Systematics, Inc.
Data provided by Caltrans and University of California at Berkeley.

Travel Time Index—A ratio of peak travel rate to a free-flow travel rate. A TTI of 1.3 indicates a 20-minute off-peak trip would take 26 minutes in the peak.

Delay per Capita—Estimate of the annual delay (in hours) per person in the urban area. Until a larger percentage of the system is instrumented, this value will be artificially low.

Percent Congested Travel—The percentage of vehicle-miles of travel that occur below 60 mph.

Buffer Index—The percentage of time above the average necessary to allow travelers to arrive on time for 95% of trips. The difference between the 95th and average travel rate divided by the average travel rate.

Misery Rate—The length of delay for the most congested 20% of the trips. The average travel rate is subtracted from the average rate for the slowest 20% of the trips. The Misery Rate is a percentage of extra time needed for the worst 20% of the trips.

Percent Variation—The amount of extra time needed to be on time for 85% of the trips. Calculated as the standard deviation divided by the average travel rate.

An exhibit will be inserted here to illustrate annual trends once we have more than 1 year of data.

Exhibit F-2. Los Angeles, California Regional Area
(Source: California DOT, http://www.dot.ca.gov/traffic/)

<u>Routes included in the performance measure estimates:</u>
CA 60 (EB 24.00 mi, WB 24.00 mi)
I-10 (EB 12.57 mi, WB 23.7 mi)
I-105 (EB 16.00 mi)
I-110 (NB 12.55 mi)
I-210 (EB 23.90 mi, WB 23.90 mi)
I-5 (NB 39.10 mi, SB 39.10 mi)
I-605 (NB 26.00 mi, SB 26.00 mi)
I-710 (NB 11.49 mi, SB 11.49 mi)
US 101 (SB 15.50 mi)

Where and When Delay Occurs

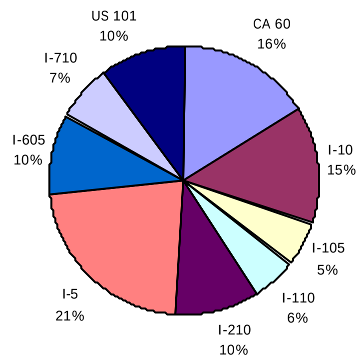


Exhibit F-3. Delay by Roadway

- I-5 has the greatest share of delay.
- I-10 and CA60 also have significant delay values.

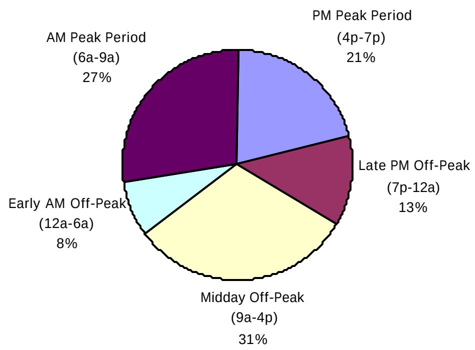


Exhibit F-4. Delay by Time of Day

- The morning and evening peak periods include only half of the total delay.
- The 13-hour peak is alive and well on many L.A. freeways.

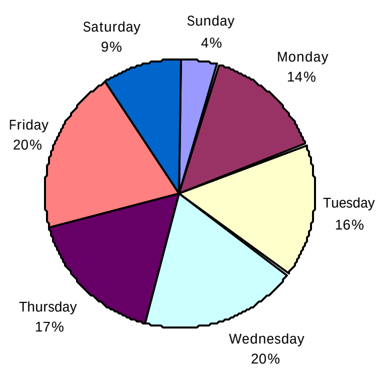
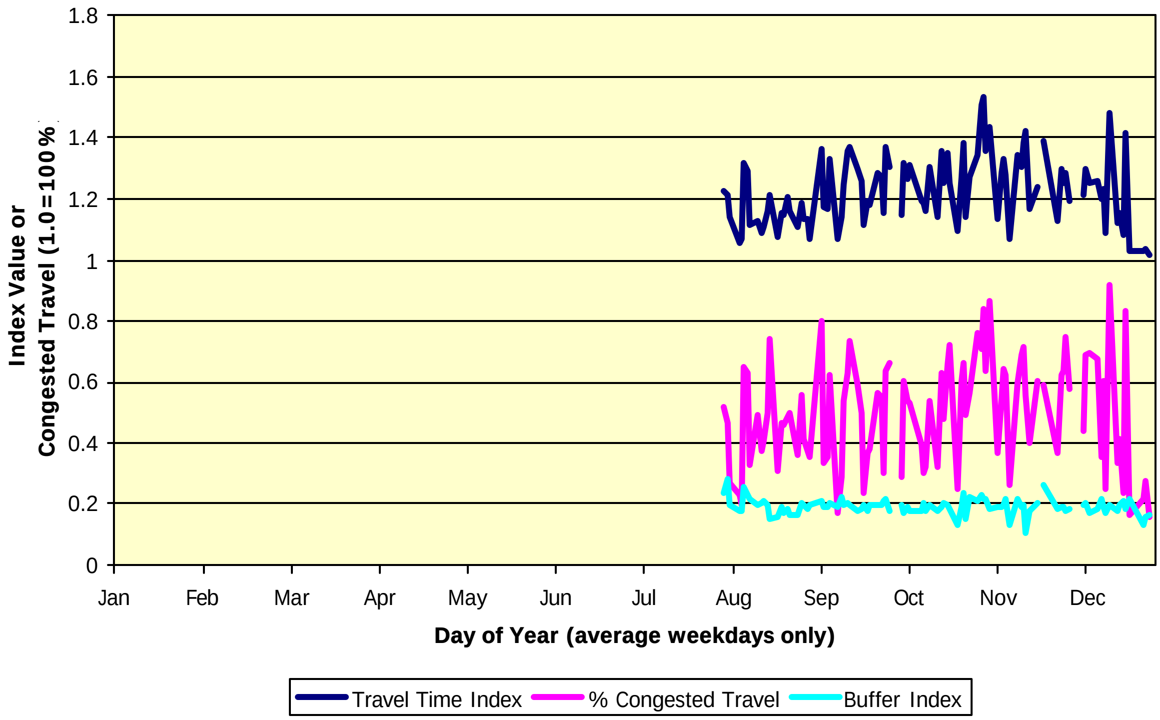


Exhibit F-5. Delay by Day of Week

- Wednesday and Friday delay is the highest.
- Weekend delay is a relatively low component of weekly delay.
- Monday delay is lower than the other weekdays.



Note: Trend lines will be added to this graph when data from a sufficient time has been collected. Until multiple years of data are analyzed, the apparent trend may only be a seasonal variation in travel conditions.

Exhibit F-6. Mobility and Reliability Measures by Day of the Year

- Travel times and congested travel show a lot of variation from day-to-day.
- Unreliability (measured by the Buffer Index) remained at a relatively low constant level because the Los Angeles data was summarized to the corridor section level. This removed a source of variation—station-to-station along the freeway—that is present in all other cities.

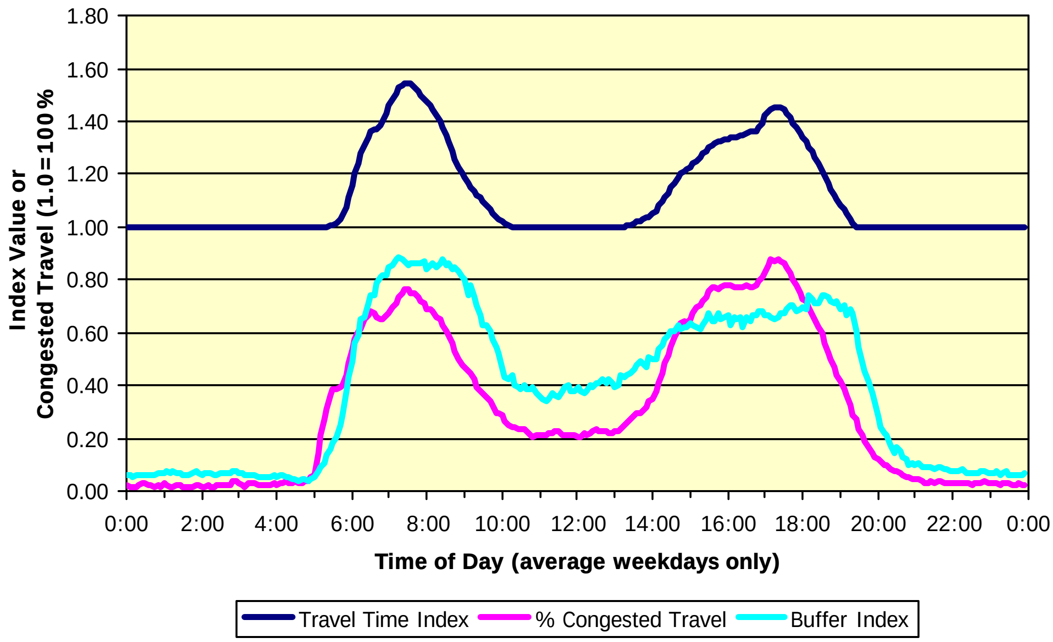


Exhibit F-7. Mobility and Reliability Measures by Time of an Average Day

- The morning peak congestion level is worse but the evening peak lasts longer.
- Congested travel approaches 80% in the morning and 90% in the evening.
- Reliability is slightly better in the evening but both peaks suffer reliability problems.
- Reliability is very good in the overnight period.

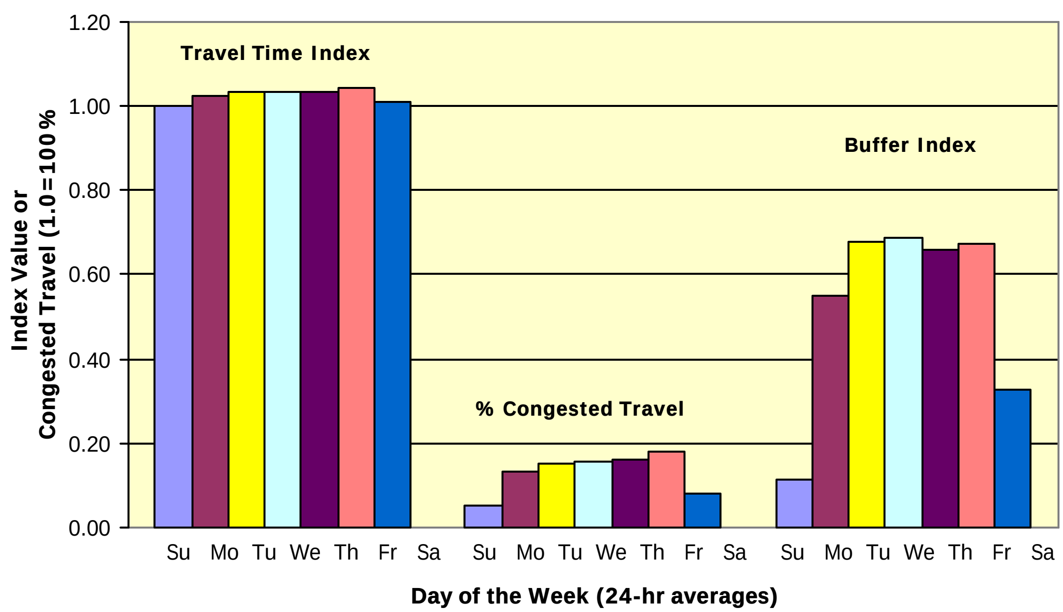


Exhibit F-8. Mobility and Reliability Measures by Day of an Average Week

- Reliability problems peak on Wednesday, but weekday Buffer Index values are among the highest in the study.

2000 MOBILITY AND RELIABILITY REPORT—
BY DIRECTIONAL SECTION, LOS ANGELES, CA

Exhibit F-9. Top Ten List—Most Congested Peak Periods

Rank	Directional Section	Date	Time Period	Travel Time Index
1	US 101 SB	October 4, 2000	AM Peak Period	4.28
2	I-5 NB	October 27, 2000	AM Peak Period	3.88
3	I-5 NB	October 11, 2000	AM Peak Period	3.87
4	I-110 NB	October 11, 2000	AM Peak Period	3.68
5	I-10 EB	September 15, 2000	PM Peak Period	3.55
6	I-5 NB	November 13, 2000	AM Peak Period	3.54
7	I-10 EB	August 25, 2000	PM Peak Period	3.44
8	I-10 EB	October 30, 2000	PM Peak Period	3.39
9	US 101 SB	October 11, 2000	AM Peak Period	3.37
10	I-10 WB	November 15, 2000	AM Peak Period	3.20

Exhibit F-10. Top Ten List—Least Reliable Peak Periods

Rank	Directional Section	Date	Time Period	Buffer Index
1	I-710 NB	October 27, 2000	Midday Off-Peak	226%
2	I-10 EB	September 1, 2000	Midday Off-Peak	153%
3	I-710 SB	October 23, 2000	Midday Off-Peak	153%
4	I-710 NB	October 11, 2000	Midday Off-Peak	150%
5	I-10 EB	November 13, 2000	Midday Off-Peak	135%
6	US 101 SB	October 24, 2000	Midday Off-Peak	133%
7	I-10 EB	September 15, 2000	Midday Off-Peak	132%
8	I-710 SB	September 27, 2000	Midday Off-Peak	131%
9	I-10 EB	November 22, 2000	Midday Off-Peak	131%
10	I-710 NB	October 27, 2000	Midday Off-Peak	226%

- The morning and midday of October 11 and 27 made both top ten lists.
- Morning peak periods dominate the top 10 most congested list, while the midday period includes all of the most unreliable periods.

Exhibit F-11. Travel Time Index—Los Angeles Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
I-5 NB (MP 0.00 to 16.40, 16.40 mi)	2.22	1.84	1.13	1.40	1.23	1.10	1.50
I-5 NB (MP 18.70 to 41.40, 22.70 mi)	1.00	1.01	1.01	1.43	1.32	1.02	1.09
I-5 SB (MP 16.40 to 0.00, 16.40 mi)	1.19	1.09	1.14	1.85	1.68	1.06	1.27
I-5 SB (MP 41.40 to 18.70, 22.70 mi)	1.41	1.30	1.01	1.17	1.04	1.01	1.10
I-10 EB (MP 5.23 to 17.80, 12.57 mi)	1.52	1.28	1.16	1.95	1.83	1.10	1.47
I-10 WB (MP 42.80 to 19.10, 23.70 mi)	2.11	1.92	1.00	1.05	1.01	1.04	1.17
CA 60 EB (MP 0.00 to 24.00, 24.00 mi)	1.00	1.00	1.14	1.88	1.76	1.06	1.14
CA 60 WB (MP 24.00 to 0.00, 24.00 mi)	2.01	1.55	1.01	1.12	1.03	1.03	1.20
US 101 SB (MP 18.63 to 3.13, 15.50 mi)	2.25	1.89	1.29	1.92	1.75	1.10	1.82
I-105 EB (MP 2.00 to 18.00, 16.00 mi)	1.08	1.02	1.13	1.77	1.53	1.05	1.16
I-110 NB (MP 8.75 to 21.30, 12.55 mi)	2.21	1.91	1.17	1.52	1.33	1.08	1.57
I-210 EB (MP 24.80 to 48.70, 23.90 mi)	1.00	1.00	1.01	1.46	1.30	1.01	1.09
I-210 WB (MP 48.70 to 24.80, 23.90 mi)	1.85	1.38	1.00	1.07	1.02	1.01	1.14
I-605 NB (MP 0.00 to 26.00, 26.00 mi)	1.16	1.03	1.01	1.30	1.14	1.01	1.07
I-605 SB (MP 26.00 to 0.00, 26.00 mi)	1.36	1.21	1.01	1.26	1.13	1.03	1.17
I-710 NB (MP 6.31 to 17.80, 11.49 mi)	1.60	1.24	1.02	1.27	1.11	1.03	1.17
I-710 SB (MP 17.80 to 6.31, 11.49 mi)	1.17	1.04	1.01	1.44	1.21	1.02	1.10
CORRIDOR AVERAGE	**1.54**	**1.34**	**1.07**	**1.46**	**1.32**	**1.04**	**1.33**

Note: These performance measures represent the portion (329.3 miles) of the total freeway system (641 miles) that contains ITS traffic monitoring sensors.

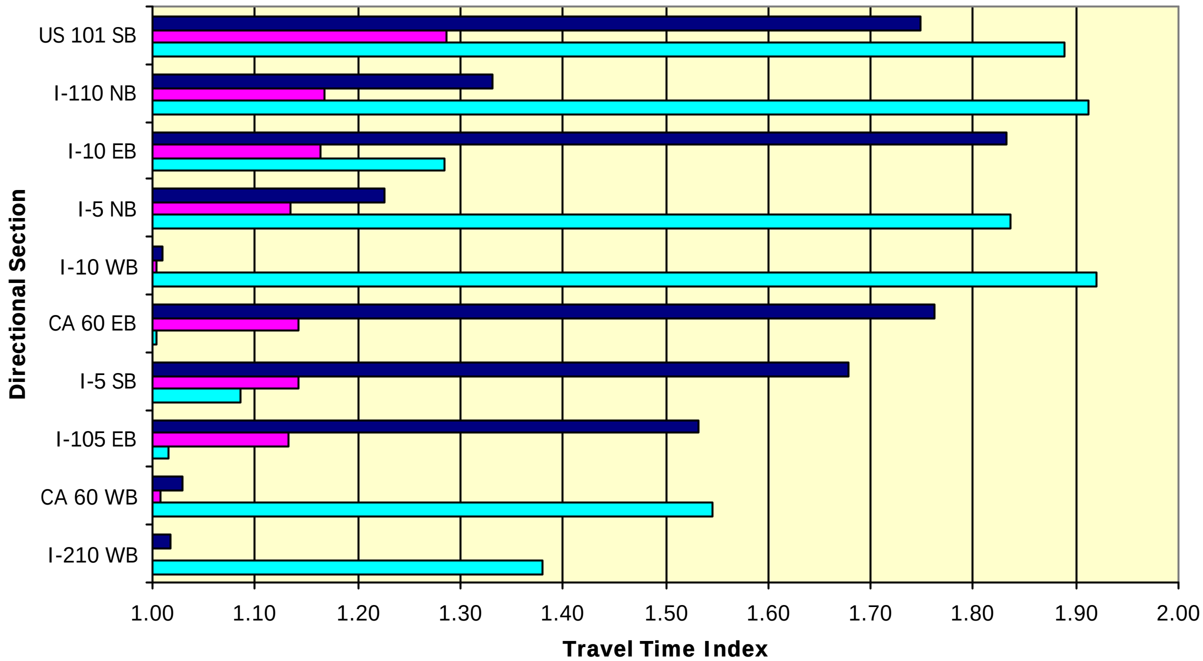


Exhibit F-12. Travel Time Index, by Directional Section

- Almost all of the freeway sections show a very directional congestion pattern.
- US 101 SB has significant congestion in both peaks.
- Midday congestion is significant only on US 101 SB.
- Five freeway sections have morning peak hour TRI values in excess of 2.0.
- Four freeway section shave morning peak period TRI values greater than 1.8.

Exhibit F-13. Buffer Index—Los Angeles Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
I-5 NB (MP 0.00 to 16.40, 16.40 mi)	59%	62%	59%	45%	46%	77%	54%
I-5 NB (MP 18.70 to 41.40, 22.70 mi)	22%	17%	30%	28%	30%	37%	24%
I-5 SB (MP 16.40 to 0.00, 16.40 mi)	78%	61%	64%	41%	44%	65%	53%
I-5 SB (MP 41.40 to 18.70, 22.70 mi)	45%	50%	36%	92%	74%	42%	61%
I-10 EB (MP 5.23 to 17.80, 12.57 mi)	53%	61%	71%	65%	70%	76%	65%
I-10 WB (MP 42.80 to 19.10, 23.70 mi)	44%	53%	32%	25%	26%	80%	40%
CA 60 EB (MP 0.00 to 24.00, 24.00 mi)	15%	15%	63%	49%	49%	68%	34%
CA 60 WB (MP 24.00 to 0.00, 24.00 mi)	43%	53%	40%	34%	33%	73%	44%
US 101 SB (MP 18.63 to 3.13, 15.50 mi)	61%	74%	59%	47%	54%	76%	64%
I-105 EB (MP 2.00 to 18.00, 16.00 mi)	22%	21%	60%	36%	34%	59%	28%
I-110 NB (MP 8.75 to 21.30, 12.55 mi)	39%	49%	54%	54%	56%	71%	52%
I-210 EB (MP 24.80 to 48.70, 23.90 mi)	8%	6%	27%	42%	46%	41%	29%
I-210 WB (MP 48.70 to 24.80, 23.90 mi)	44%	56%	16%	29%	31%	59%	44%
I-605 NB (MP 0.00 to 26.00, 26.00 mi)	29%	34%	36%	53%	55%	36%	44%
I-605 SB (MP 26.00 to 0.00, 26.00 mi)	37%	39%	31%	31%	35%	34%	37%
I-710 NB (MP 6.31 to 17.80, 11.49 mi)	79%	79%	54%	47%	57%	60%	68%
I-710 SB (MP 17.80 to 6.31, 11.49 mi)	37%	37%	53%	44%	51%	47%	44%
CORRIDOR AVERAGE	**42%**	**45%**	**46%**	**45%**	**46%**	**59%**	**46%**

Note: These performance measures represent the portion (104.3 miles) of the total freeway system (641 miles) that contains ITS traffic monitoring sensors.

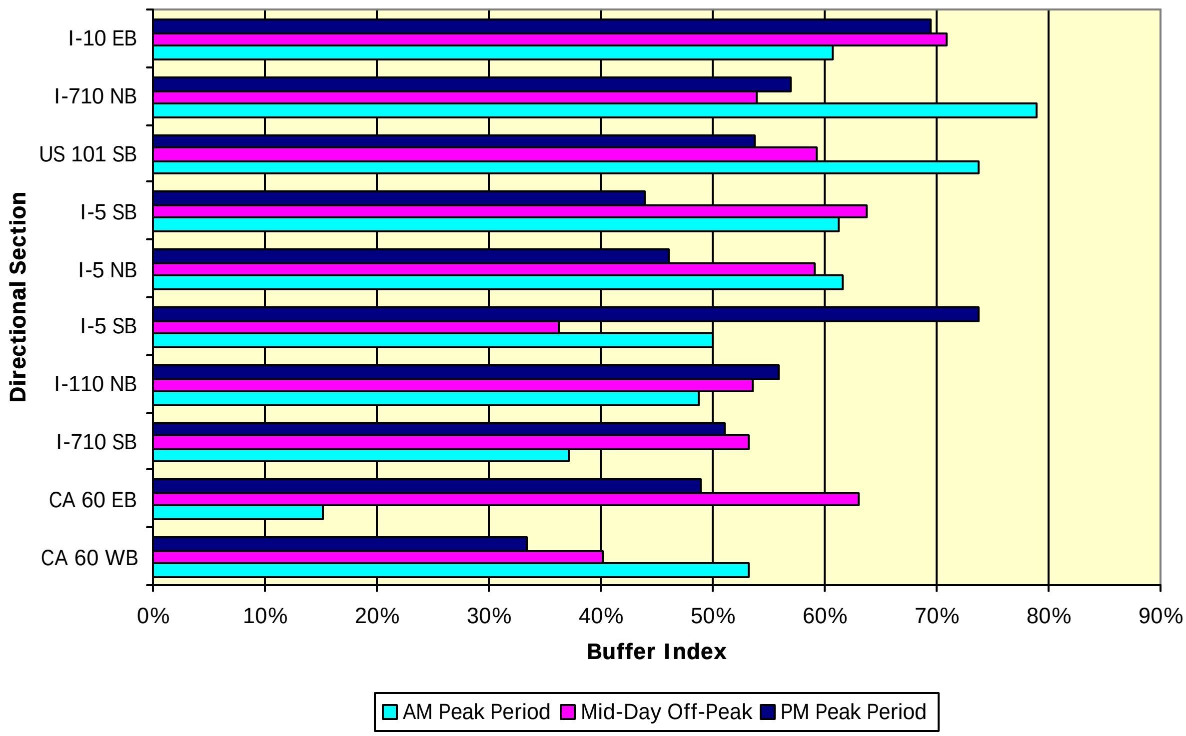


Exhibit F-14. Buffer Index, by Directional Section

- Reliability is approximately the same for both peaks on I-10 EB, US 101 SB, I-110 NB.
- Midday reliability is the most significant problem on CA 60 EB, which has a relatively low peak congestion level.
- Evening peaks are typically less reliable than the morning peak.

Appendix G—Minneapolis-St. Paul, MN

2000 Regional Mobility and Reliability Data

A Supplement to:

Monitoring Urban Roadways: Using Archived Operations Data for Reliability and Mobility Measurement by Texas Transportation Institute and Cambridge Systematics, Inc., May 2001

Minneapolis-St. Paul, MN Findings

- The database included a few high-level arterial streets, as well as freeways.
- Midday delay appears to have more delay than either peak. This may be the result of the speed estimation process, or it could reflect persistent low levels of delay over much of the system for many hours.
- The October ramp meter shut-off can be seen in the data—more congestion and less reliability.
- Weekend delay levels are relatively low.
- Winter weather problems caused congestion and reliability problems in January and December.
- Congestion and unreliability both peak at about 8 a.m. and 5:30 p.m.

Minneapolis-St. Paul, MN Data Source

- Approximately 190 miles of the more than 300-mile freeway system is included in the archived data system. Minnesota DOT provided the data.
- The data was collected primarily using single inductive loops. Speeds were estimated using local procedures. The data was reported by lane at 5-minute intervals.
- 99% of the volume and 87% of the speed data in the original data archive passed the initial quality control tests.
- The original data records included volume data for 94% of the time periods in 2000. Speed is calculated using the single loop data and a locally developed procedure.
- After removing data that failed the quality control checks and identifying missing data, data for 93% of the possible speed and 87% of the possible volume records were found to be usable for further analysis.

Major Study Findings (Why you should read the Final Report)

- It is only 36 pages.
- Local data archiving occurs in some areas but easy accessibility and use of that data is much less widespread. Database management and analytical methods can be somewhat complex, and limited local resources and guidance have also hindered widespread development of easy-to-use data archives. Each area has essentially pursued their own development schedule and scope with funding from local sources. The report, and the associated best practices guide can assist agencies in the data archiving process.
- The mobility and reliability measures used in the report can most efficiently be used for local area trend analysis and analysis of important subjects at the national level. The data are less useful for city-to-city comparisons because of the incomplete ITS coverage and inconsistencies between cities. The report summarizes the measures used in the study and demonstrates how they can be prepared and interpreted.

Exhibit G-1. Trends in Mobility and Reliability Indicators

Indicator	2000	1999	Change
MOBILITY			
Travel Time Index	1.06		
Delay per Capita (hours)	10.3		
Percent Congested Travel	12%		
RELIABILITY			
Buffer Index	64%		
Misery Rate	33%		
Percent Variation	51%		

Notes: [1]These performance measures represent the portion (192 miles) of the total freeway system (311 miles) that contains ITS traffic monitoring sensors.
[2]All statistics reported in this exhibit are peak period averages for all weekdays in the year indicated (no holidays included).
[3]This exhibit will be used to illustrate annual trends once we have more than one year of data.
[4]Annual average conditions are affected by the October ramp meter shut off.

Data analysis by Texas Transportation Institute and Cambridge Systematics, Inc.
Data provided by Minnesota DOT.

Travel Time Index—A ratio of peak travel rate to a free-flow travel rate. A TTI of 1.3 indicates a 20-minute off-peak trip would take 26 minutes in the peak.
Delay per Capita—Estimate of the annual delay (in hours) per person in the urban area. Until a larger percentage of the system is instrumented, this value will be artificially low.
Percent Congested Travel—The percentage of vehicle-miles of travel that occur below 60 mph.
Buffer Index—The percentage of time above the average necessary to allow travelers to arrive on time for 95% of trips. The difference between the 95th and average travel rate divided by the average travel rate.
Misery Rate—The length of delay for the most congested 20% of the trips. The average travel rate is subtracted from the average rate for the slowest 20% of the trips. The Misery Rate is a percentage of extra time needed for the worst 20% of the trips.
Percent Variation—The amount of extra time needed to be on time for 85% of the trips. Calculated as the standard deviation divided by the average travel rate.

An exhibit will be inserted here to illustrate annual trends once we have more than 1 year of data.

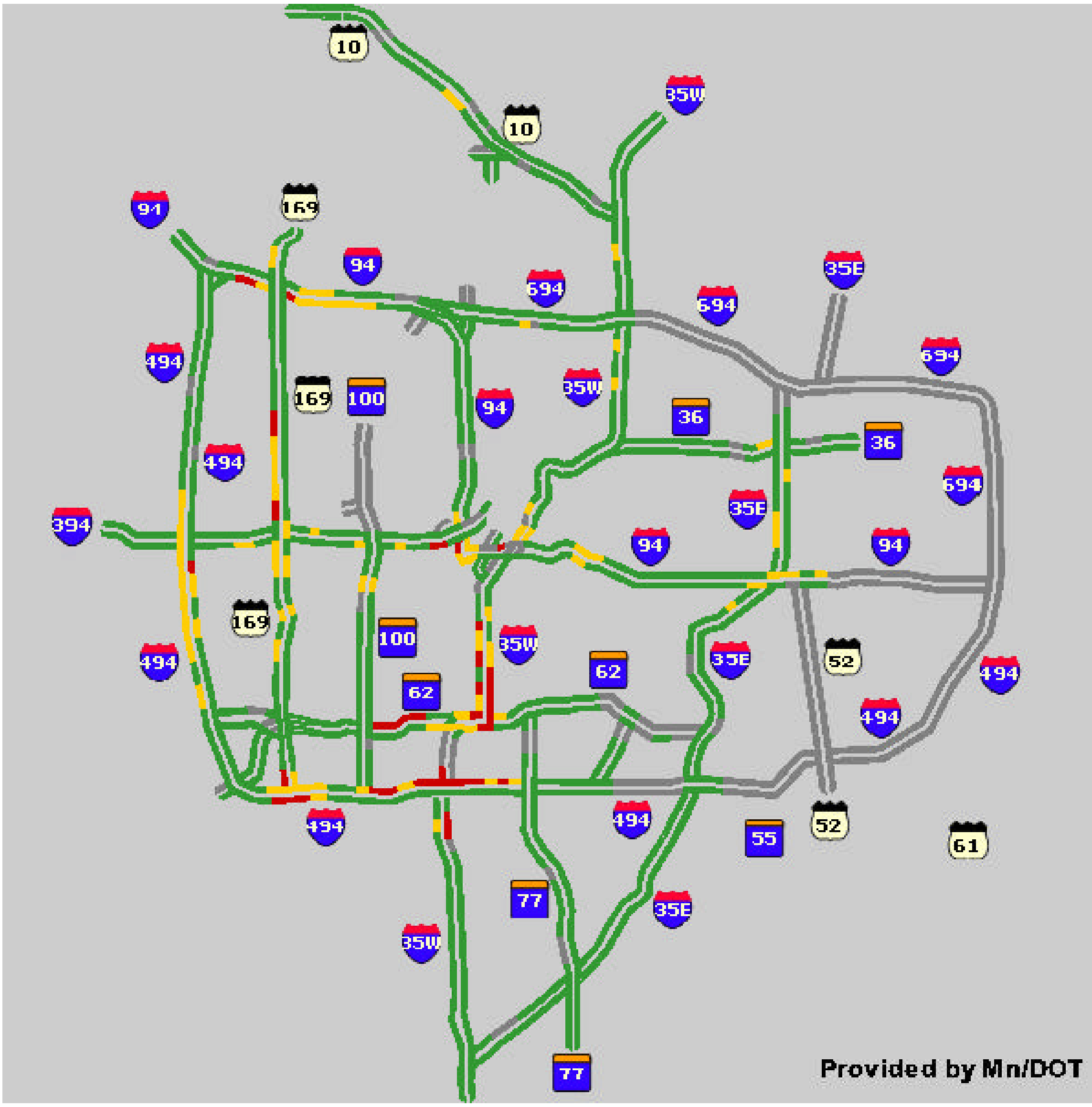


Exhibit G-2. Minneapolis-St. Paul, Minnesota Regional Area
(Source: Minnesota DOT's Traffic Management Center,
http://www.dot.state.mn.us/tmc/trafficinfo/map/refreshmap.html)

Routes included in performance measure estimates:

MN 5 (EB 2.11 mi, WB 1.99 mi)
US 12 (EB 2.38 mi, WB 2.39 mi)
TH 13 (1.00 mi)
MN 36 (EB 7.62 mi, WB 7.61 mi)
MN 55 (NB 1.00 mi, SB 0.50 mi)
MN 62 (EB 12.93 mi, WB 12. 39 mi)
MN 77 (NB 5.13 mi, SB 5.12 mi)
I-94 (EB 28.41 mi, WB 28.42 mi)
US 100 (NB 10.37 mi, SB 10.12 mi)
TH 110 (NB 0.50 mi)
US 169 (NB 16.76 mi, SB 16.86 mi)
US 212 (NB 2.86 mi, SB 2.84 mi)
I-394 (EB 9.04 mi, WB 10.18 mi)
I-494 (EB 27.76 mi, WB 30.83 mi)
I-604 (EB 6.48 mi, WB 5.36 mi)
I-35E (NB 33.07 mi, SB 33.80 mi)
I-35W (NB 23.61 mi, SB 23.69 mi)

Where and When Delay Occurs

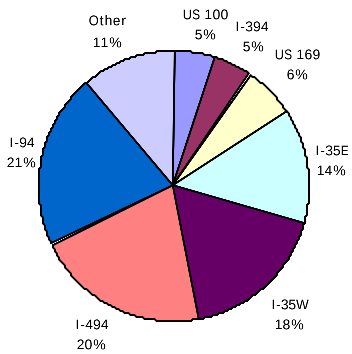


Exhibit G-3. Delay by Roadway

- ♦ Three facilities have a significant share of delay.

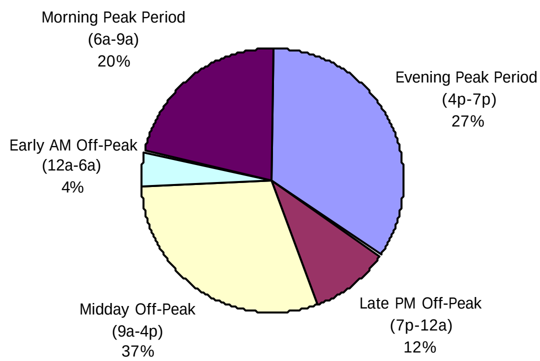


Exhibit G-4. Delay by Time of Day

- ♦ The midday off-peak period has more delay than either of the traditional peak periods.
- ♦ The evening peak is more congested than the morning.
- ♦ The late night and early morning off-peaks account for 16 percent of delay.

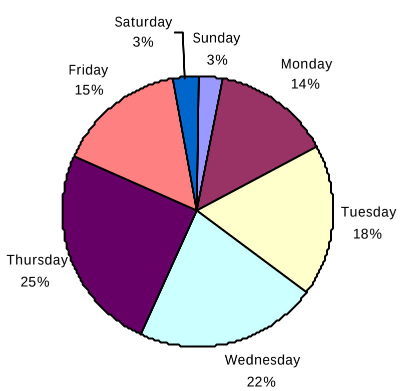
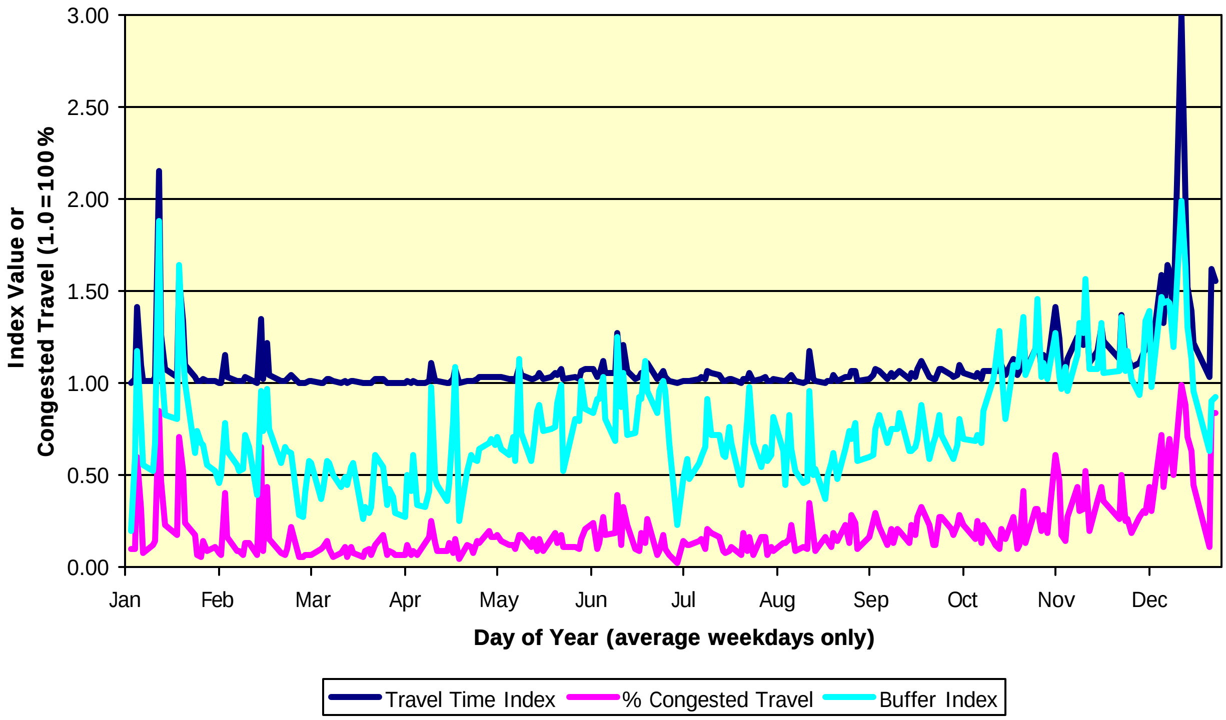


Exhibit G-5. Delay by Day of Week

- ♦ Weekend delay is less than half the typical weekday delay.
- ♦ Delay peaks on Wednesday and Thursday at levels significantly higher than Monday or Friday. This may be partly influenced by government holidays.



Note: Trend lines will be added to this graph when data from a sufficient time has been collected. Until multiple years of data are analyzed, the apparent trend may only be a seasonal variation in travel conditions.

Exhibit G-6. Mobility and Reliability Measures by Day of the Year

- March, July and August are the most reliable months.
- Winter weather problems caused spikes in congestion and unreliability in January and December—some of the highest in the 10 cities studied.
- The effect of the October ramp meter shut off can be seen in both the increased congestion and decreased reliability.
- The average weekday peak period TRI was close to 1.0 for many days when the ramp meters were turned on; a few days were very high.

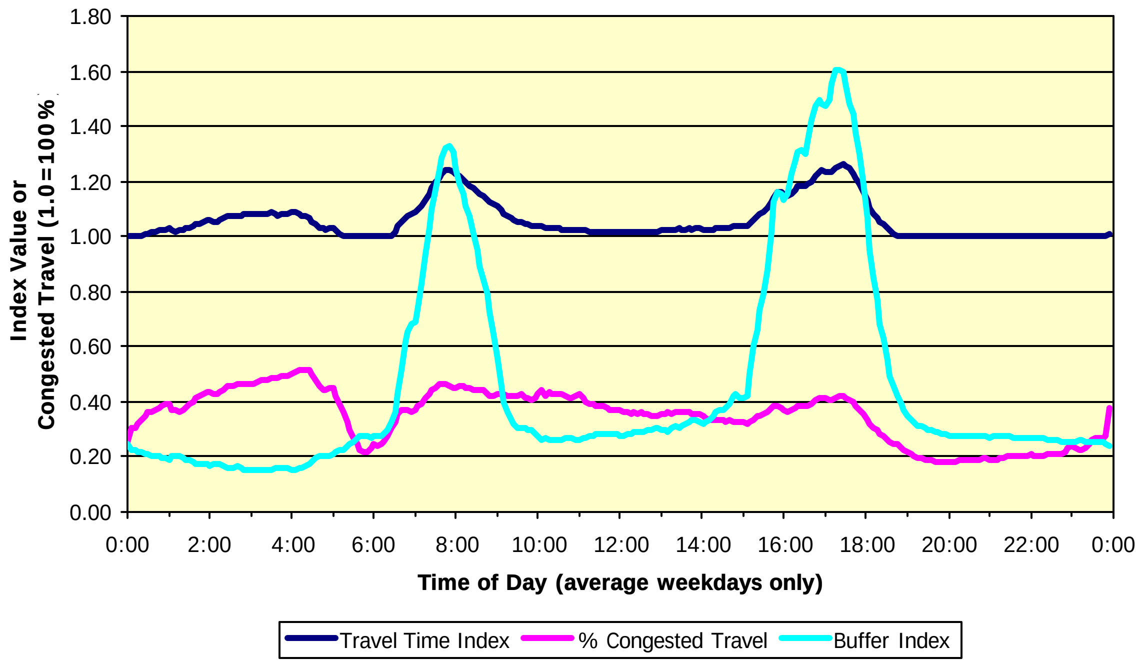


Exhibit G-7. Mobility and Reliability Measures by Time of an Average Day

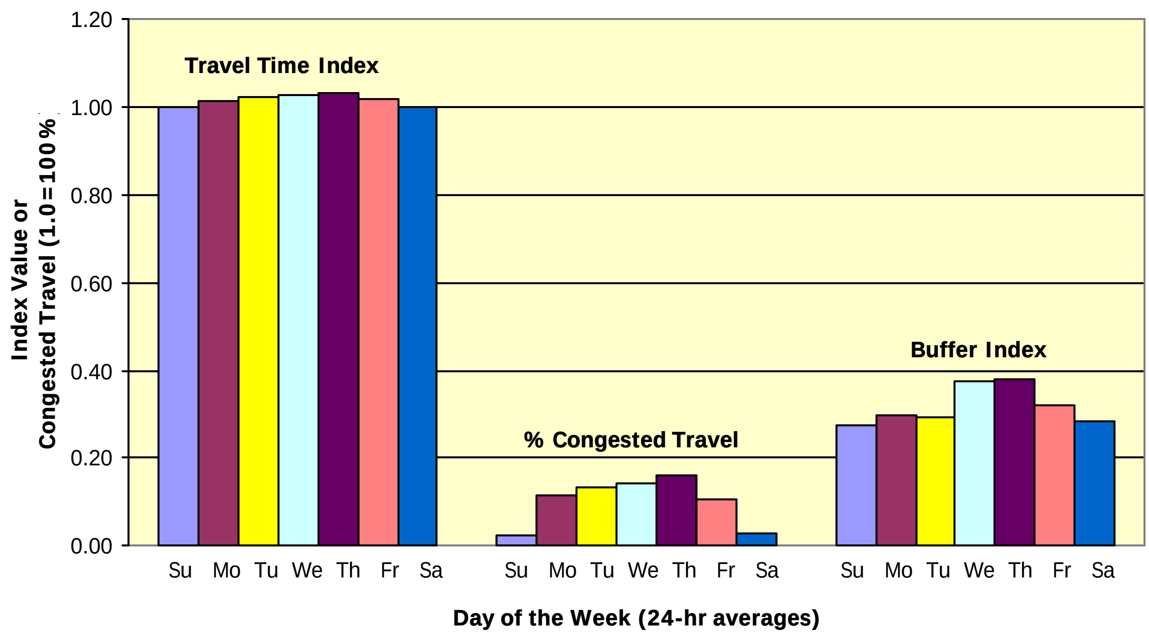


Exhibit G-8. Mobility and Reliability Measures by Day of an Average Week

- Unreliability peaks on Wednesday and Thursday—the most congested days.
- The effect of Monday or Friday holidays does not seem to be great—the variation in travel conditions are not much greater than for Tuesday.
- Congestion and unreliability peak at about the same time—8 a.m. and 5:30 p.m.
- Percent congested travel declines prior to the peak as travelers try to "beat the rush."
- Evening peak periods last longer than the morning.

Exhibit G-9. Top Ten List—Most Congested Peak Periods

Rank	Directional Section	Date	Time Period	Travel Time Index
1	MN 77 SB	December 18, 2000	PM Peak Period	8.85
2	MN 36 WB	December 18, 2000	AM Peak Period	5.51
3	MN 77 SB	January 12, 2000	PM Peak Period	5.20
4	US 100 NB	January 12, 2000	PM Peak Period	5.11
5	I-494 EB	December 18, 2000	PM Peak Period	4.80
6	US 100 NB	December 18, 2000	PM Peak Period	4.79
7	MN 5 EB	December 18, 2000	PM Peak Period	4.68
8	US 169 NB	December 18, 2000	PM Peak Period	4.58
9	I-35E (S) SB	December 18, 2000	AM Peak Period	4.40
10	MN 77 SB	December 13, 2000	PM Peak Period	4.29

Exhibit G-10. Top Ten List—Least Reliable Peak Periods

Rank	Directional Section	Date	Time Period	Buffer Index
1	MN 77 NB	December 12, 2000	AM Peak Period	926%
2	MN 77 NB	December 18, 2000	AM Peak Period	758%
3	I-694 WB	September 13, 2000	AM Peak Period	739%
4	MN 77 NB	January 20, 2000	AM Peak Period	633%
5	MN 62 EB	October 24, 2000	Midday Off-Peak	599%
6	I-35E (S) NB	August 9, 2000	PM Peak Period	511%
7	TH 13 EB & WB	June 22, 2000	PM Peak Period	507%
8	US 169 SB	August 4, 2000	PM Peak Period	505%
9	I-494 EB	August 4, 2000	PM Peak Period	500%
10	I-394 WB	January 19, 2000	PM Peak Period	498%

- A few significant weather days are identified in the data—widespread and significant congestion.
- MN 77 and I-694 have relatively little recurring congestion, so incidents and weather show more prominently in the corridor reliability statistics.
- Reliability list numbers 8 and 9 are related—US 169 connects to I-494.
- The lack of off-peak periods in the reliability table may be a reflection of the operations efforts of MnDOT.
- The ramp meter shut off does not appear to be illustrated in the Top 10 lists.

Exhibit G-11. Travel Time Index—Minneapolis-St. Paul Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
MN 5, EB (Post Rd to TH 55, 2.11 mi)	1.02	1.02	1.02	1.09	1.03	1.03	1.03
MN 5, WB (TH 55 to Post Rd, 1.99 mi)	1.00	1.00	1.00	1.03	1.00	1.00	1.00
US 12, EB (Central Ave to I-494, 2.38 mi)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
US 12, WB (I-494 to Central Ave, 2.39 mi)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
TH 13 (I-35W, 1.00 mi)	1.38	1.33	1.28	1.28	1.26	1.26	1.29
MN 36, EB (TH 280 to MN 61, 7.62 mi)	1.07	1.02	1.02	1.32	1.13	1.03	1.08
MN 36, WB (MN 61 to Cleveland, 7.61 mi)	1.50	1.16	1.01	1.01	1.01	1.03	1.06
MN 55, NB (TH 100 to TH 110, 1.00 mi)	1.34	1.33	1.37	1.33	1.34	1.33	1.33
MN 55, SB (TH 110 to TH 100, 0.50 mi)	1.38	1.39	1.42	1.38	1.37	1.33	1.37
MN 62, EB (Rowland to TH 5, 12.93 mi)	1.27	1.20	1.21	1.96	1.73	1.26	1.46
MN 62, WB (TH 5 to Rowland, 12.39 mi)	1.40	1.27	1.08	1.31	1.18	1.12	1.23
MN 77, NB (CR 38 to TH 62, 5.13 mi)	1.09	1.02	1.01	1.00	1.00	1.01	1.01
MN 77, SB (TH 77 to Nicols, 5.12 mi)	1.00	1.00	1.00	1.04	1.00	1.00	1.00
I-94, EB (Weaver Lake to Mounds, 28.41 mi)	1.19	1.09	1.03	1.26	1.12	1.05	1.11
I-94, WB (Mounds to Weaver Lake, 28.41 mi)	1.12	1.07	1.03	1.23	1.08	1.04	1.07
US 100, NB (77th St to Duluth, 10.37 mi)	1.15	1.07	1.03	1.50	1.20	1.06	1.13
US 100, SB (Duluth to 77th St, 10.12 mi)	1.11	1.04	1.02	1.26	1.06	1.03	1.05
TH 110, NB (TH 55, 0.50 mi)	1.00	1.01	1.10	1.06	1.02	1.03	1.01
US 169, NB (76th St to 77th Ave, 16.76 mi)	1.00	1.01	1.03	1.49	1.12	1.04	1.07
US 169, SB (77th Ave to 76th St, 16.86 mi)	1.41	1.19	1.04	1.13	1.04	1.05	1.07
US 212, NB (Valley View to TH 169, 2.86 mi)	1.02	1.01	1.04	1.24	1.09	1.04	1.05
US 212, SB (TH 169 to I-494, 2.84 mi)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
I-394, EB (I-494 to Linden Ave, 9.04 mi)	1.26	1.07	1.01	1.24	1.09	1.02	1.08
I-394, WB (7th St to I-494, 10.18 mi)	1.00	1.01	1.01	1.38	1.12	1.02	1.06
I-494, EB (I-94 to TH 5, 27.76 mi)	1.16	1.07	1.05	1.29	1.15	1.06	1.11
I-494, WB (TH 5 to I-394, 30.83 mi)	1.31	1.21	1.08	1.34	1.14	1.08	1.17

Exhibit G-11. Continued

I-694, EB (Shingle Creek to I-35W, 6.48 mi)	1.00	1.00	1.00	1.07	1.00	1.00	1.00
I-694, WB (I-35W to TH 252, 5.36 mi)	1.13	1.02	1.00	1.00	1.00	1.00	1.00
I-35E (S), NB (Oakcrest to Lexington, 10.21 mi)	1.00	1.00	1.01	1.14	1.03	1.00	1.02
I-35E (N), NB (Southcross to Little Canada, 22.86 mi)	1.07	1.05	1.05	1.22	1.12	1.06	1.08
I-35E (S), SB (Oakcrest to Lexington, 11.39 mi)	1.31	1.05	1.00	1.00	1.00	1.00	1.00
I-35E (N), SB (Little Canada to Southcross, 22.41 mi)	1.22	1.13	1.04	1.04	1.04	1.05	1.07
I-35W, NB (CR 42 to TH 36, 23.61 mi)	1.16	1.07	1.01	1.11	1.05	1.02	1.06
I-35W, SB (TH 36 to CR 42, 23.69 mi)	1.16	1.08	1.05	1.21	1.09	1.04	1.09
CORRIDOR AVERAGE	**1.19**	**1.08**	**1.04**	**1.23**	**1.04**	**1.04**	**1.06**

Note: These performance measures represent the portion (192 miles) of the total freeway system (311 miles) that contains ITS traffic monitoring sensors.

- HOV lanes are included as part of each corridor—their contribution improves the congestion picture for those sections.
- The daily averages are relatively unremarkable.
- Only 3 segments have peak period averages greater than 1.3, but 17 such instances are recorded for the peak hour.
- MN 5 and MN 55 are high-level arterial streets.

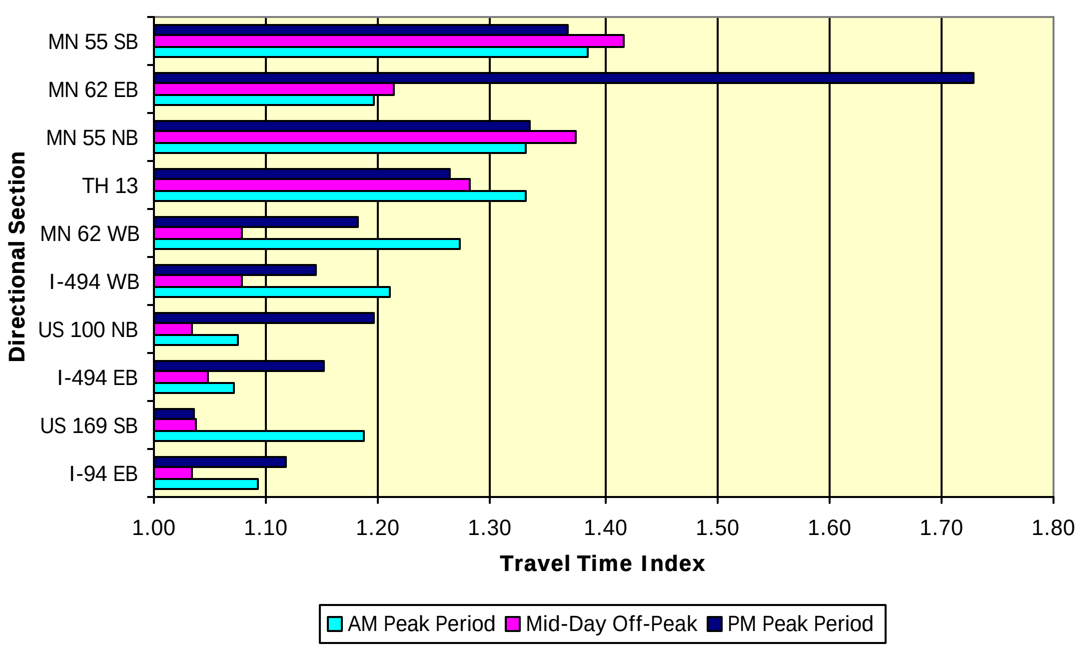


Exhibit G-12. Travel Time Index, by Ten Most Congested Directional Sections

Exhibit G-13. Buffer Index—Minneapolis-St. Paul Annual Summary, Year 2000

CORRIDOR	Morning		Midday	Afternoon		Daily	Avg. Peak Period
	Peak Hour (7a-8a)	Peak Period (6a-9a)	(9a-4p)	Peak Hour (5p-6p)	Peak Period (4p-7p)	(24 hr)	(am & pm)
MN 5, EB (Post Rd to TH 55, 2.11 mi)	12%	12%	8%	19%	13%	11%	13%
MN 5, WB TH 55 to Post Rd, 1.99 mi)	12%	13%	9%	17%	12%	15%	12%
US 12, EB (Central Ave to I-494, 2.38 mi)	20%	15%	9%	11%	10%	20%	13%
US 12, WB (I-494 to Central Ave, 2.39 mi)	12%	14%	11%	12%	10%	20%	11%
TH 13 (I-35W, 1.00 mi)	18%	16%	16%	15%	13%	14%	14%
MN 36, EB (TH 280 to MN 61, 7.62 mi)	29%	27%	28%	138%	112%	25%	85%
MN 36, WB (MN 61 to Cleveland, 7.61 mi)	151%	140%	29%	30%	30%	24%	92%
MN 55, NB (TH 100 to TH 110, 1.00 mi)	18%	17%	12%	17%	14%	13%	16%
MN 55, SB TH 110 to TH 100, 0.50 mi)	12%	12%	12%	16%	11%	12%	11%
MN 62, EB (Rowland to TH 5, 12.93 mi)	118%	119%	120%	190%	184%	107%	153%
MN 62, WB (TH 5 to Rowland, 12.39 mi)	115%	100%	18%	159%	73%	18%	87%
MN 77, NB (CR 38 to TH 62, 5.13 mi)	189%	120%	23%	30%	30%	27%	84%
MN 77, SB (TH 77 to Nicols, 5.12 mi)	17%	18%	18%	34%	14%	20%	15%
I-94, EB (Weaver Lake to Mounds, 28.41 mi)	147%	104%	31%	136%	118%	36%	110%
I-94, WB (Mounds to Weaver Lake, 28.41 mi)	75%	63%	36%	152%	136%	35%	103%
US 100, NB (77th St to Duluth, 10.37 mi)	108%	62%	31%	230%	214%	27%	148%
US 100, SB (Duluth to 77th St, 10.12 mi)	138%	105%	23%	158%	125%	21%	115%
TH 110, NB (TH 55, 0.50 mi)	40%	37%	31%	48%	44%	31%	41%
US 169, NB (76th St to 77th Ave, 16.76 mi)	27%	20%	22%	237%	191%	24%	117%
US 169, SB (77th Ave to 76th St, 16.86 mi)	183%	164%	15%	123%	39%	22%	109%
US 212, NB (Valley View to TH 169, 2.86 mi)	15%	14%	13%	30%	8%	14%	11%
US 212, SB (TH 169 to I-494, 2.84 mi)	12%	11%	11%	11%	9%	18%	10%
I-394, EB (I-494 to Linden Ave, 9.04 mi)	84%	87%	34%	125%	110%	44%	98%
I-394, WB (7th St to I-494, 10.18 mi)	23%	22%	19%	133%	139%	24%	86%
I-494, EB (I-94 to TH 5, 27.76 mi)	165%	134%	45%	173%	140%	52%	136%
I-494, WB (TH 5 to I-394, 30.83 mi)	129%	111%	88%	187%	170%	74%	144%

Exhibit G-13. Continued

I-694, EB (Shingle Creek to I-35W, 6.48 mi)	50%	28%	12%	242%	152%	24%	94%
I-694, WB (I-35W to TH 252, 5.36 mi)	130%	70%	12%	36%	24%	22%	47%
I-35E (S), NB (Oakcrest to Lexington, 10.21 mi)	13%	14%	16%	119%	100%	19%	77%
I-35E (N), NB (Southcross to Little Canada, 22.86 mi)	81%	54%	41%	123%	94%	37%	73%
I-35E (S), SB (Oakcrest to Lexington, 11.39 mi)	161%	134%	15%	21%	18%	23%	95%
I-35E (N), SB (Little Canada to Southcross, 22.41 mi)	74%	48%	34%	75%	48%	30%	48%
I-35W, NB (CR 42 to TH 36, 23.61 mi)	107%	88%	37%	108%	88%	41%	88%
I-35W, SB (TH 36 to CR 42, 23.69 mi)	87%	75%	65%	118%	107%	65%	92%
CORRIDOR AVERAGE	**43%**	**36%**	**27%**	**62%**	**45%**	**23%**	**41%**

Note: These performance measures represent the portion (192 miles) of the total freeway system (311 miles) that contains ITS traffic monitoring sensors.

- MN 62 EB and I-494 WB are consistently unreliable.
- The expressway sections are some of the most reliable corridors.
- The evening peaks are less reliable than the morning.
- The highest buffer index values correspond to the peak direction of a facility. Often this is a very congested section, but several unreliable corridors are only somewhat congested.

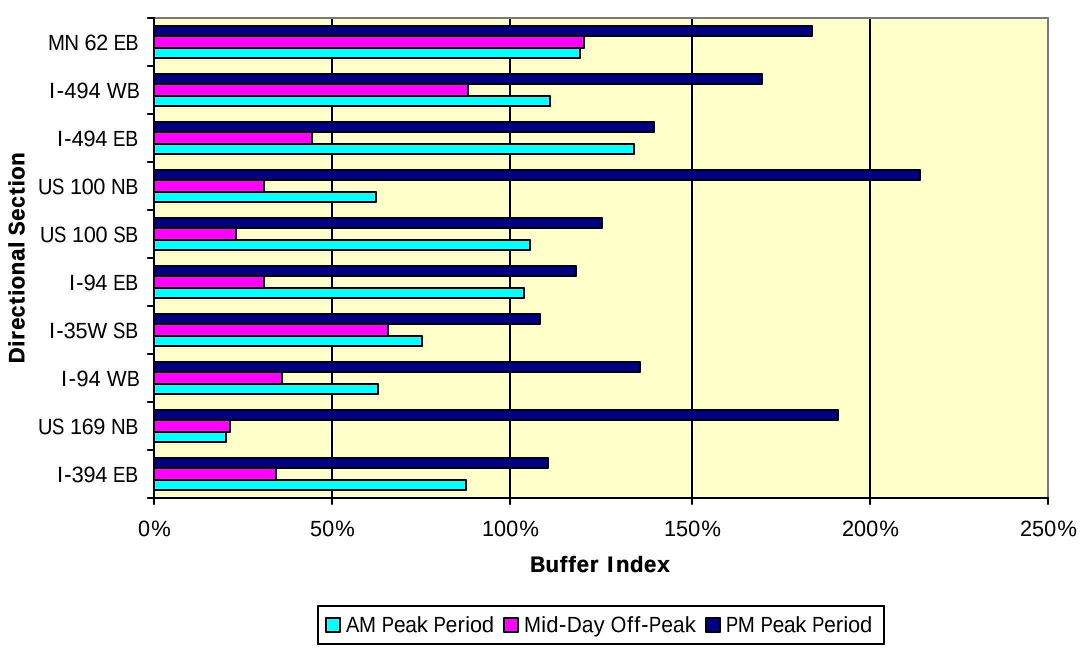


Exhibit G-14. Buffer Index, by Ten Least Reliable Directional Sections

Appendix H—Phoenix, AZ

2000 Regional Mobility and Reliability Data

A Supplement to:

Monitoring Urban Roadways: Using Archived Operations Data for Reliability and Mobility Measurement by Texas Transportation Institute and Cambridge Systematics, Inc., May 2001

Phoenix, AZ Findings

- Midday delay is equal to the evening peak period delay.
- Late-evening and early-morning delay combined is almost as significant as the evening peak.
- Weekend days combined have as much delay as a typical weekday.
- May to September has less congestion and more reliability than other months. This appears to show the effect of the increased winter population.
- The congested period lasts longer in the evening than the morning.

Phoenix, AZ Data Source

- Approximately 53 of the 138-mile freeway system is included in the archived data system. Data was provided by Arizona DOT.
- The data was collected primarily using double inductive loops, with some passive acoustic detectors. Direct speed estimates are obtained. The data was reported by lane by direction at 5-minute intervals.
- 94% of volume and 84% of the speed data in the original data archive passed the initial quality control tests.
- The original data records included volume and speed for 78% of the time periods in 2000.
- After removing data that failed the quality control checks and identifying missing data, 74% of the possible volume, but only 37% of the speed records were found to be usable for further analysis.

Major Study Findings (Why you should read the Final Report)

- It is only 36 pages.
- Local data archiving occurs in some areas but easy accessibility and use of that data is much less widespread. Database management and analytical methods can be somewhat complex, and limited local resources and guidance have also hindered widespread development of easy-to-use data archives. Each area has essentially pursued their own development schedule and scope with funding from local sources. The report, and the associated best practices guide can assist agencies in the data archiving process.
- The mobility and reliability measures used in the report can most efficiently be used for local area trend analysis and analysis of important subjects at the national level. The data are less useful for city-to-city comparisons because of the incomplete ITS coverage and inconsistencies between cities. The report summarizes the measures used in the study and demonstrates how they can be prepared and interpreted.

Exhibit H-1. Trends in Mobility and Reliability Indicators

Indicator	2000	1999	Change
MOBILITY			
Travel Time Index	1.11		
Delay per Capita (hours)	2.56		
Percent Congested Travel	49%		
RELIABILITY			
Buffer Index	43%		
Misery Rate	27%		
Percent Variation	33%		

Notes: [1]These performance measures represent the portion (53.4 miles) of the total freeway system (138 miles) that contains ITS traffic monitoring sensors.
[2]All statistics reported in this exhibit are peak period averages for all weekdays in the year indicated (no holidays included).
[3]This exhibit will be used to illustrate annual trends once we have more than one year of data.

Data analysis by Texas Transportation Institute and Cambridge Systematics, Inc.
Data provided by Arizona DOT.

Travel Time Index—A ratio of peak travel rate to a free-flow travel rate. A TTI of 1.3 indicates a 20-minute off-peak trip would take 26 minutes in the peak.
Delay per Capita—Estimate of the annual delay (in hours) per person in the urban area. Until a larger percentage of the system is instrumented, this value will be artificially low.
Percent Congested Travel—The percentage of vehicle-miles of travel that occur below 60 mph.
Buffer Index—The percentage of time above the average necessary to allow travelers to arrive on time for 95% of trips. The difference between the 95th and average travel rate divided by the average travel rate.
Misery Rate—The length of delay for the most congested 20% of the trips. The average travel rate is subtracted from the average rate for the slowest 20% of the trips. The Misery Rate is a percentage of extra time needed for the worst 20% of the trips.
Percent Variation—The amount of extra time needed to be on time for 85% of the trips. Calculated as the standard deviation divided by the average travel rate.

An exhibit will be inserted here to illustrate annual trends once we have more than 1 year of data.

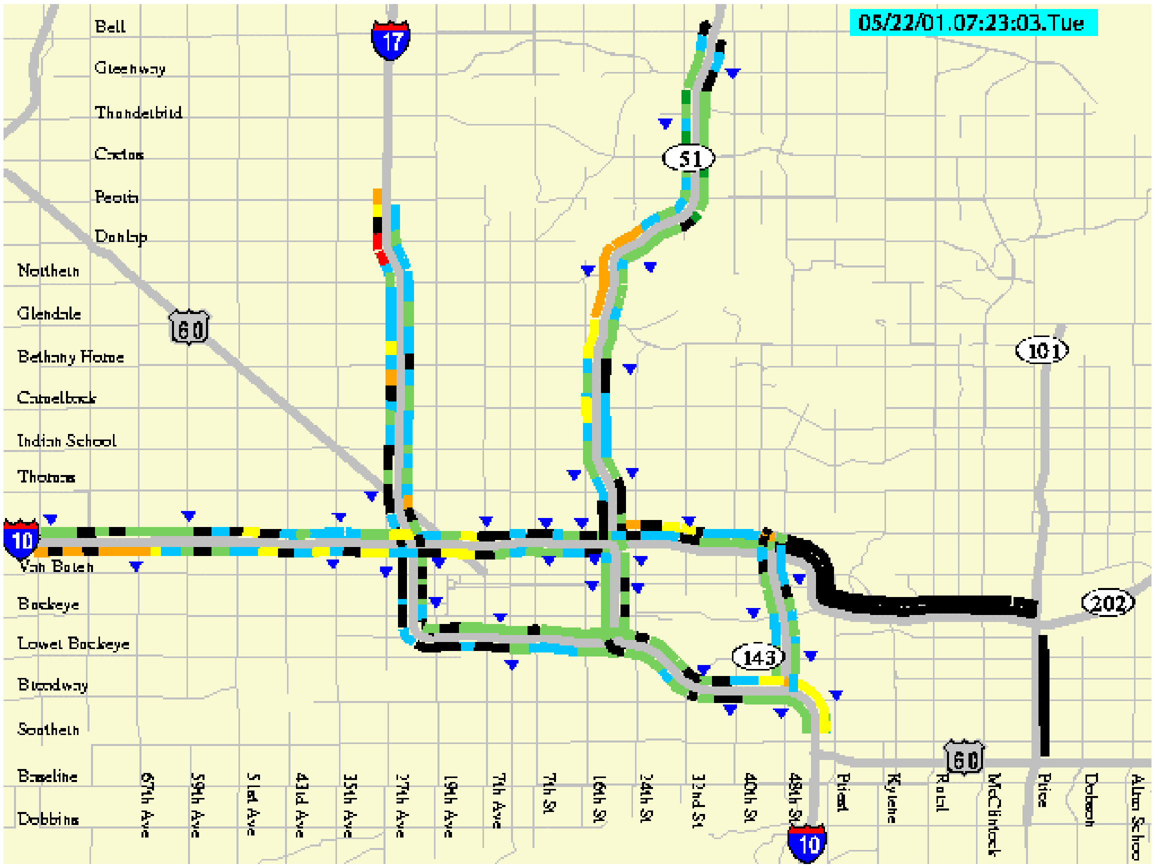


Exhibit H-2. Phoenix, Arizona Regional Area
(Source: Arizona DOT's Freeway Management System, http://www.azfms.com/Travel/freeway.html)

Routes included in performance measure estimates:
I-10 (EB 18.94 mi, EB HOV 18.94 mi, WB 18.91 mi, WB HOV 18.91 mi)
I-17 (NB 14.46 mi, SB 14.43 mi)
Loop 202 (EB 3.02 mi, EB HOV 3.02 mi, WB 3.27, WB HOV 3.27 mi)
SR 143 (NB 3.40, SB 3.40 mi)
SR 51 (NB 13.38 mi, SB 13.32 mi)

Where and When Delay Occurs

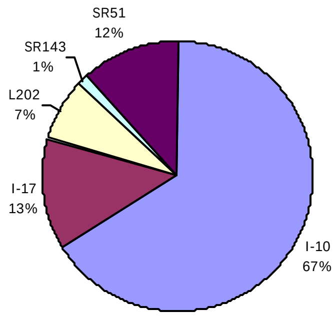


Exhibit H-3. Delay by Roadway

- A significant share of the instrumented sections are on I-10.
- There is congestion on the other roadways, but some are relatively short.

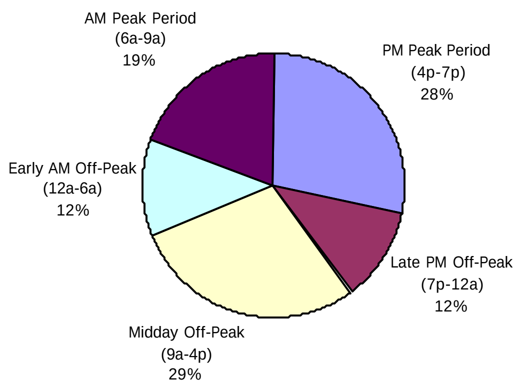


Exhibit H-4. Delay by Time of Day

- Evening delay and midday delay are about equal.
- More than ¼ of daily delay is during the midday, but it is spread over 7 hours.
- Late-evening and early-morning delay combined is almost as significant as the evening peak.

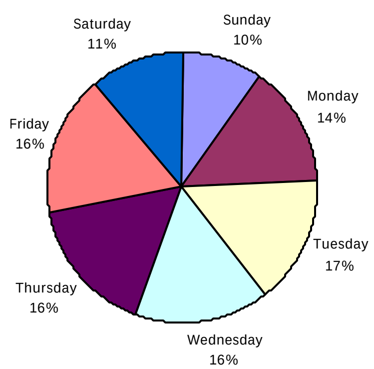
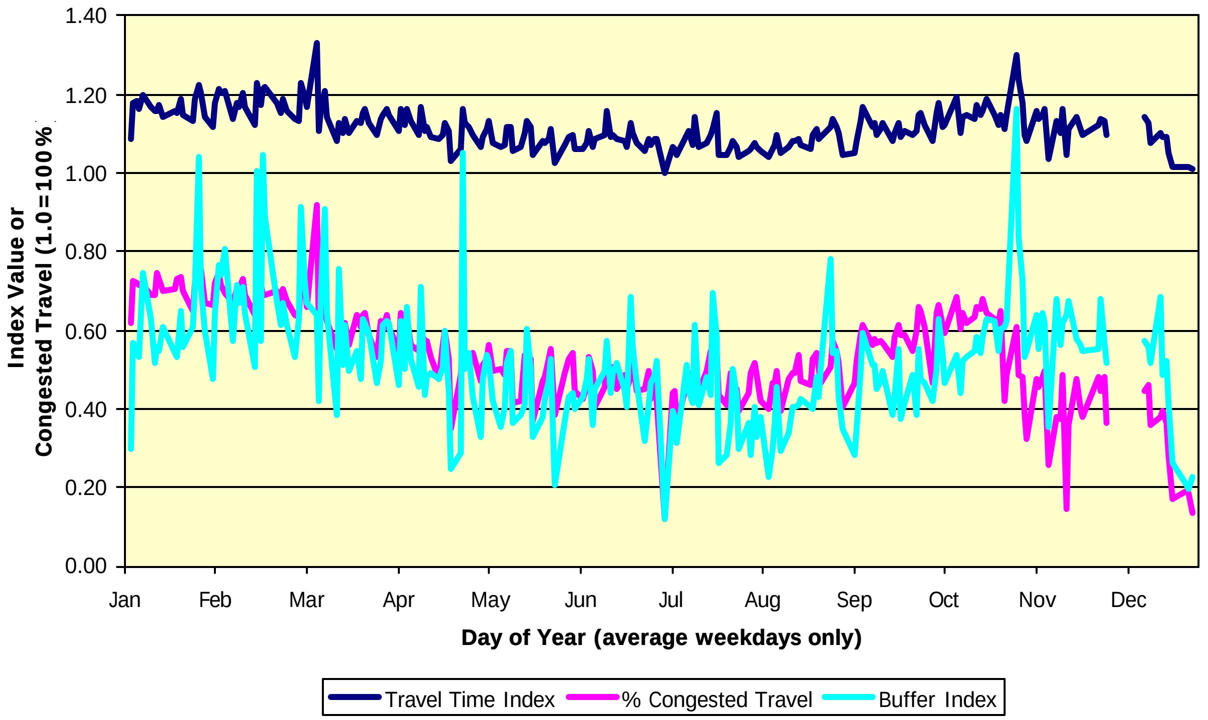


Exhibit H-5. Delay by Day of Week

- Tuesday to Friday delays are very similar.
- The weekend days combined have slightly more delay than a typical weekday.



Note: Trend lines will be added to this graph when data from a sufficient time has been collected. Until multiple years of data are analyzed, the apparent trend may only be a seasonal variation in travel conditions.

Exhibit H-6. Mobility and Reliability Measures by Day of the Year

- May to September delay is lower than the other months, possibly due to people spending the winter in Arizona.
- May to September have more reliable conditions.
- Reliability may be improving but a few very bad days in January/February/March and seasonal fluctuations may be accenting the downward trend.
- There are several very good and very bad days for reliable travel.

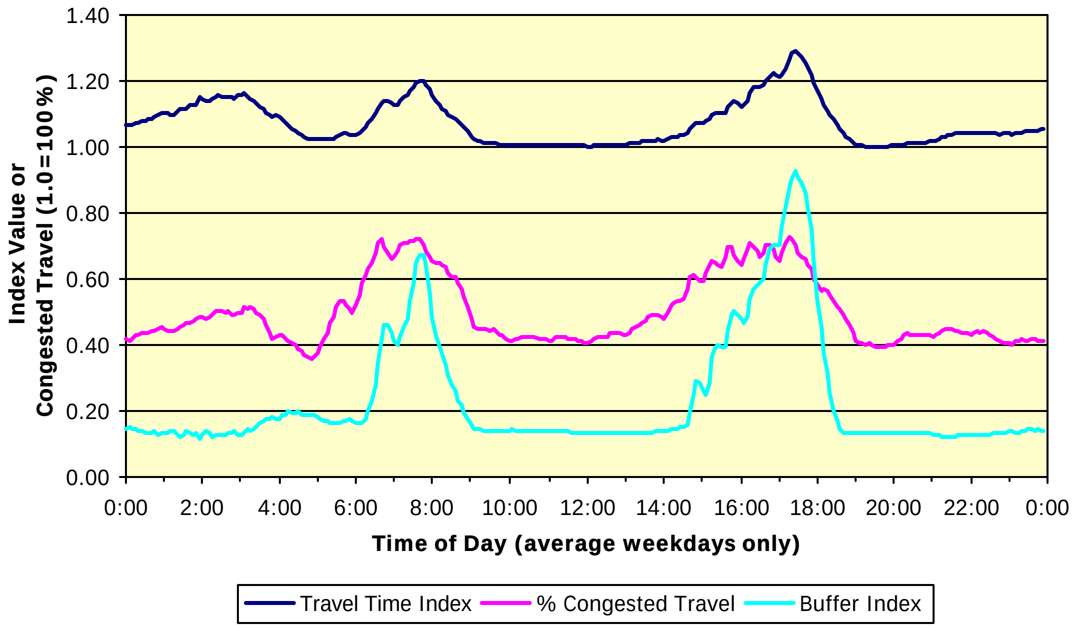


Exhibit H-7. Mobility and Reliability Measures by Time of an Average Day

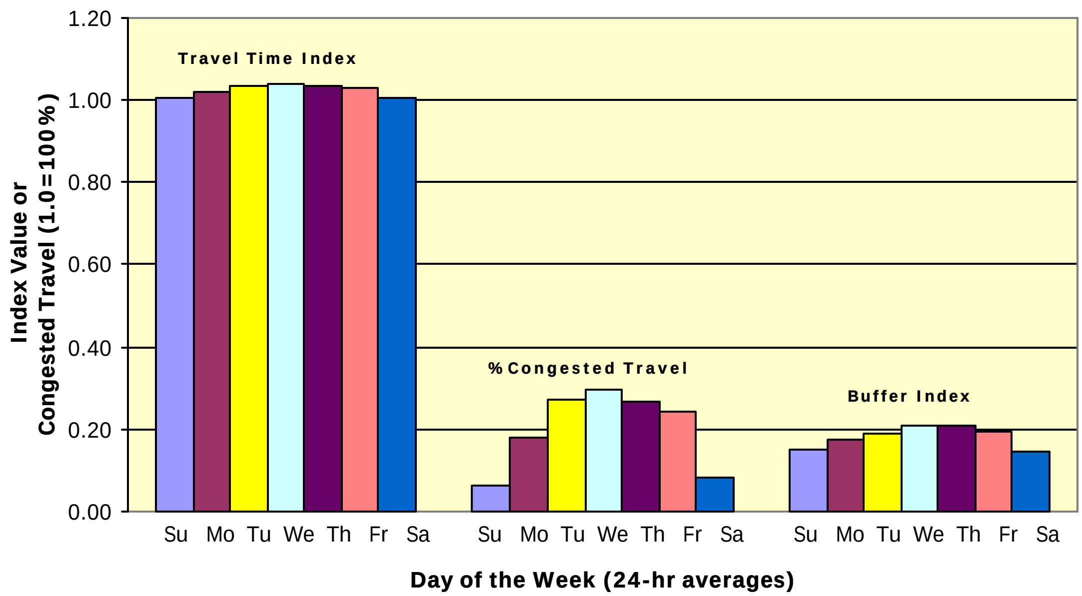


Exhibit H-8. Mobility and Reliability Measures by Day of an Average Week

- The evening peak is more congested and less reliable than other periods.
- The congested period is longer in the evening than the morning.
- The percentage of travel affected by congestion peaks at about 70%.
- The early morning "congestion" is probably due to a combination of data collection problems and slower driving speeds (particularly trucks) in relatively light traffic conditions rather than high traffic volumes. A TRI of 1.2 indicates average speeds near 50 mph, about the same as the morning peak average.

2000 MOBILITY AND RELIABILITY REPORT— BY DIRECTIONAL SECTION, PHOENIX, ARIZONA

Exhibit H-9. Top Ten List—Most Congested Peak Periods

Rank	Directional Section	Date	Time Period	Travel Time Index
1	I-17 SB	August 28, 2000	PM Peak Period	3.06
2	L202 WB	October 30, 2000	PM Peak Period	2.60
3	I-10 EB	October 27, 2000	PM Peak Period	2.36
4	I-17 NB	October 30, 2000	PM Peak Period	2.31
5	L202 WB	November 17, 2000	PM Peak Period	2.12
6	I-17 SB	November 13, 2000	AM Peak Period	2.06
7	L202 WB	October 20, 2000	PM Peak Period	2.04
8	I-17 NB	November 6, 2000	PM Peak Period	2.04
9	L202 WB	November 16, 2000	PM Peak Period	2.02
10	L202 WB	April 6, 2000	AM Peak Period	2.02

Exhibit H-10. Top Ten List—Least Reliable Peak Periods

Rank	Directional Section	Date	Time Period	Buffer Index
1	I-17 SB	August 28, 2000	Midday Off-Peak	592%
2	SR143 SB	January 21, 2000	AM Peak Period	531%
3	I-10 EB	August 28, 2000	PM Peak Period	506%
4	I-10 EB	April 25, 2000	AM Peak Period	505%
5	I-10 EB	January 26, 2000	AM Peak Period	439%
6	I-17 SB	October 30, 2000	AM Peak Period	438%
7	L202 WB	June 19, 2000	Early AM Off-Peak	432%
8	I-17 NB	January 7, 2000	AM Peak Period	427%
9	I-10 EB	February 17, 2000	AM Peak Period	419%
10	L202 WB	August 22, 2000	Midday Off-Peak	418%

- August 28 and October 30 were particularly bad congestion days.
- Six morning peak and three off-peak periods made the least reliable periods list.
- Even though the average congestion level is not high, I-17 has some significant congestion and unreliability problems.

Exhibit H-11. Travel Time Index—Phoenix Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL -SUBURBAN							
I-10 EB (81st Ave to Fairmont, 18.94 mi)	1.21	1.13	1.02	1.47	1.29	1.08	1.21
I-10 EB HOV (81st Ave to Fairmont, 18.94 mi)	1.15	1.06	1.00	1.11	1.04	1.01	1.05
I-10 WB (Fairmont to 82nd Ave, 18.91 mi)	1.10	1.07	1.04	1.25	1.16	1.06	1.11
I-10 WB HOV (Fairmont to 41st Ave, 18.91 mi)	1.03	1.02	1.01	1.22	1.11	1.03	1.06
I-17 NB (23rd St to Beryl Ave, 14.46 mi)	1.02	1.01	1.06	1.35	1.21	1.06	1.09
I-17 SB (Beryl to 22nd St, 14.43 mi)	1.28	1.20	1.05	1.05	1.03	1.07	1.10
Loop 202 EB (26th St to 46th St, 3.02 mi)	1.08	1.05	1.01	1.20	1.12	1.03	1.08
Loop 202 EB HOV (26th St to 46th St, 3.02 mi)	1.00	1.00	1.00	1.04	1.01	1.00	1.00
Loop 202 WB (46th St to 22nd St, 3.27 mi)	1.39	1.26	1.06	1.23	1.15	1.06	1.20
Loop 202 WB HOV (46th St to 22nd St, 3.27 mi)	1.07	1.01	1.00	1.03	1.01	1.00	1.01
SR143 NB (Kerby to Moreland, 3.40 mi)	1.06	1.04	1.04	1.07	1.05	1.04	1.05
SR143 SB (Willetta to Kerby, 3.40 mi)	1.08	1.04	1.02	1.14	1.08	1.03	1.06
SR51 NB (Culver to Paradise Lane, 13.38 mi)	1.06	1.04	1.02	1.16	1.09	1.04	1.06
SR51 SB (Juniper to Willetta, 13.32 mi)	1.32	1.15	1.01	1.04	1.01	1.02	1.06
CORRIDOR AVERAGE	**1.15**	**1.08**	**1.02**	**1.25**	**1.13**	**1.04**	**1.11**

Note: These performance measures represent the portion (53.4 miles) of the total freeway system (138 miles) that contains ITS traffic monitoring sensors.

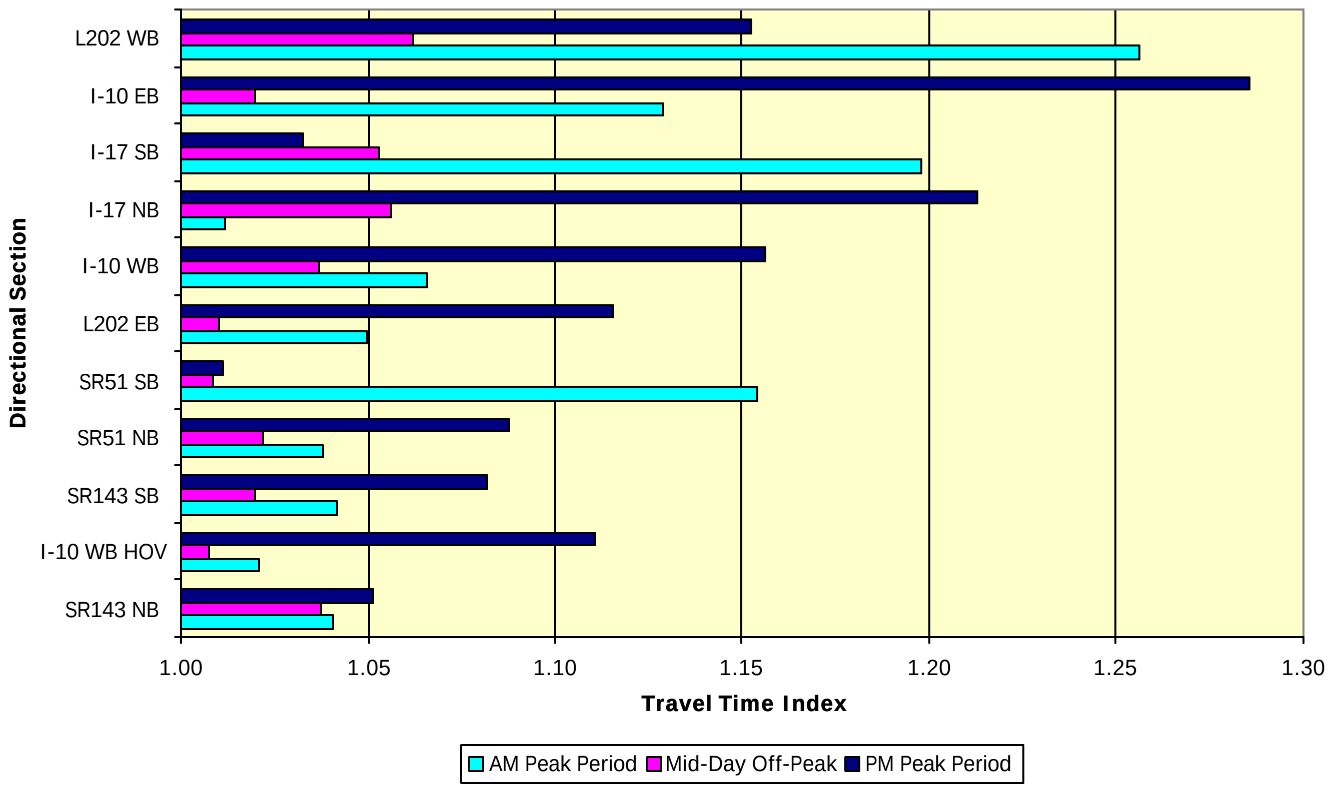


Exhibit H-12. Travel Time Index, by Directional Section

- Evening peaks are more congested in most corridors.
- Midday periods show little to no congestion.
- I-10 EB peaks are more congested than I-10 WB peaks.
- Evening I-17 SB exhibits very high peaking—the peak hour contains all of the congestion in the period.

Exhibit H-13. Buffer Index—Phoenix Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL –SUBURBAN							
I-10 EB (81st Ave to Fairmont, 18.94 mi)	118%	94%	15%	117%	103%	38%	98%
I-10 EB HOV (81st Ave to Fairmont, 18.94 mi)	41%	20%	10%	29%	26%	20%	24%
I-10 WB (Fairmont to 82nd Ave, 18.91 mi)	38%	31%	18%	100%	82%	28%	56%
I-10 WB HOV (Fairmont to 41st Ave, 18.91 mi)	16%	15%	17%	64%	45%	18%	33%
I-17 NB (23rd St to Beryl Ave, 14.46 mi)	12%	11%	20%	120%	104%	26%	61%
I-17 SB (Beryl to 22nd St, 14.43 mi)	78%	61%	11%	15%	12%	16%	40%
Loop 202 EB (26th St to 46th St, 3.02 mi)	22%	13%	10%	71%	47%	10%	31%
Loop 202 EB HOV (26th St to 46th St, 3.02 mi)	9%	8%	7%	20%	14%	9%	12%
Loop 202 WB (46th St to 22nd St, 3.27 mi)	70%	73%	49%	111%	99%	50%	85%
Loop 202 WB HOV (46th St to 22nd St, 3.27 mi)	17%	18%	15%	24%	22%	15%	20%
SR143 NB (Kerby to Moreland, 3.40 mi)	7%	8%	8%	8%	8%	9%	8%
SR143 SB (Willetta to Kerby, 3.40 mi)	54%	54%	58%	47%	52%	56%	53%
SR51 NB (Culver to Paradise Lane, 13.38 mi)	18%	18%	17%	40%	39%	21%	30%
SR51 SB (Juniper to Willetta, 13.32 mi)	89%	69%	17%	18%	17%	18%	48%
CORRIDOR AVERAGE	**63%**	**51%**	**17%**	**79%**	**68%**	**27%**	**43%**

Note: These performance measures represent the portion (53.4 miles) of the total freeway system (138 miles) that contains ITS traffic monitoring sensors.

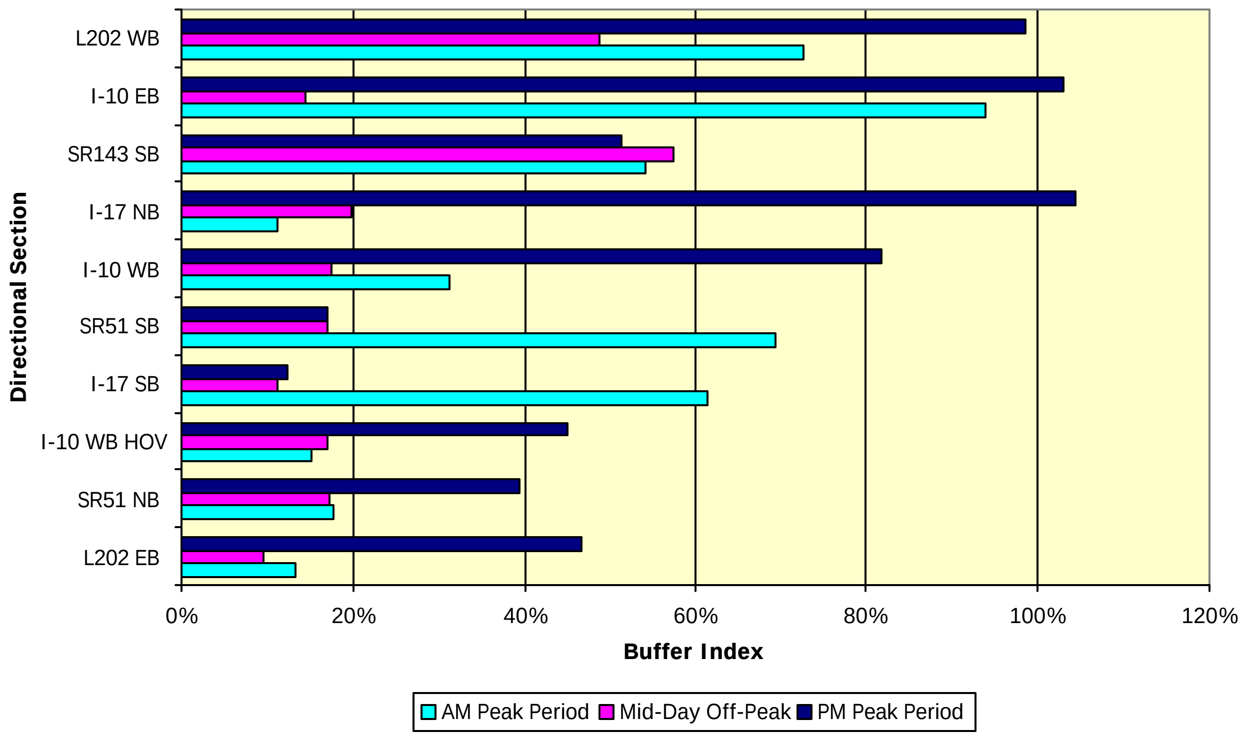


Exhibit H-14. Buffer Index, by Directional Section

- The evening peak is much less reliable than morning, in all but I-10 EB, the most congested corridor.
- I-10 EB is significantly less reliable than other corridors.
- Midday reliability is good on most freeways.
- The high congestion level on I-17 SB evening peak period also results in very unreliable conditions.

Appendix I—San Antonio, TX

2000 Regional Mobility and Reliability Data

A Supplement to:

Monitoring Urban Roadways: Using Archived Operations Data for Reliability and Mobility Measurement by Texas Transportation Institute and Cambridge Systematics, Inc., May 2001

San Antonio, TX Findings

- Evening peak delay is 1/3 of total delay.
- Midday delay is greater than morning peak delay.
- Weekend delay is equal to a typical weekday.
- A few congestion and unreliability spikes were found in the data during the year, but almost all peak periods had relatively low congestion levels.
- The morning and evening congested periods did not last as long as in some other cities.
- The peak hour Buffer Index values are relatively high.

San Antonio, TX Data Source

- Approximately 68 miles of the 211-mile freeway system is included in the archived data system. The data was provided by Texas DOT
- The data was collected primarily using double inductive loops and a limited number of acoustic detectors. Direct speed estimates are obtained from this equipment. Data from the AVI system was not very extensive and did not cover the entire year. The AVI system is also being phased out by TxDOT. Data was reported by lane at 20- to 30-second intervals.
- 99% of both the volume and speed data in the original data archive passed the initial quality control tests.
- The original records included volume data for 76% and speed data for 62% of the time periods in 2000.
- After removing data that failed the quality control checks and identifying missing data, about 62% of the possible speed and volume records were found to be usable for further analysis.

Major Study Findings (Why you should read the Final Report)

- It is only 36 pages.
- Local data archiving occurs in some areas but easy accessibility and use of that data is much less widespread. Database management and analytical methods can be somewhat complex, and limited local resources and guidance have also hindered widespread development of easy-to-use data archives. Each area has essentially pursued their own development schedule and scope with funding from local sources. The report, and the associated best practices guide can assist agencies in the data archiving process.
- The mobility and reliability measures used in the report can most efficiently be used for local area trend analysis and analysis of important subjects at the national level. The data are less useful for city-to-city comparisons because of the incomplete ITS coverage and inconsistencies between cities. The report summarizes the measures used in the study and demonstrates how they can be prepared and interpreted.

Exhibit I-1. Trends in Mobility and Reliability Indicators

Indicator	2000	1999	Change
MOBILITY			
Travel Time Index	1.08		
Delay per Capita (hours)	4.0		
Percent Congested Travel	35%		
RELIABILITY			
Buffer Index	32%		
Misery Rate	14%		
Percent Variation	25%		

Notes: [1]These performance measures represent the portion (67.9 miles) of the total freeway system (211 miles) that contains ITS traffic monitoring sensors.

[2]All statistics reported in this exhibit are peak period averages for all weekdays in the year indicated (no holidays included).

[3]This exhibit will be used to illustrate annual trends once we have more than one year of data.

Data analysis by Texas Transportation Institute and Cambridge Systematics, Inc.
Data provided by Texas DOT.

Travel Time Index—A ratio of peak travel rate to a free-flow travel rate. A TTI of 1.3 indicates a 20-minute off-peak trip would take 26 minutes in the peak.
Delay per Capita—Estimate of the annual delay (in hours) per person in the urban area. Until a larger percentage of the system is instrumented, this value will be artificially low.
Percent Congested Travel—The percentage of vehicle-miles of travel that occur below 60 mph.
Buffer Index—The percentage of time above the average necessary to allow travelers to arrive on time for 95% of trips. The difference between the 95th and average travel rate divided by the average travel rate.
Misery Rate—The length of delay for the most congested 20% of the trips. The average travel rate is subtracted from the average rate for the slowest 20% of the trips. The Misery Rate is a percentage of extra time needed for the worst 20% of the trips.
Percent Variation—The amount of extra time needed to be on-time for 85% of the trips. Calculated as the standard deviation divided by the average travel rate.

An exhibit will be inserted here to illustrate annual trends once we have more than 1 year of data.

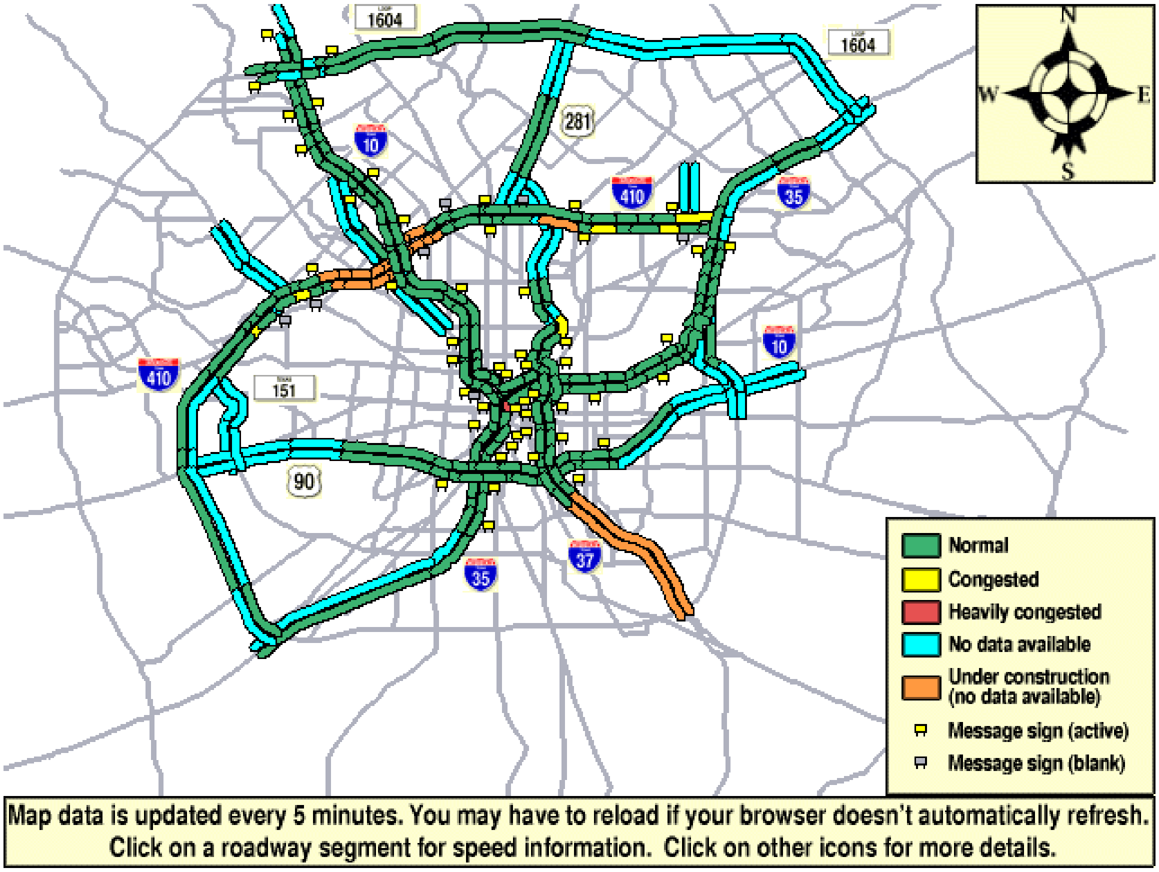


Exhibit I-2. San Antonio, Texas Regional Area
(Source: Texas DOT's TransGuide, http://www.transguide.dot.state.tx.us)

Routes included in performance measure estimates:

I-10 (EB 21.01 mi, WB 24.39 mi)
I-35 (NB 18.09 mi, SB 18.73 mi)
I-37 (NB 4.76 mi, SB 4.54 mi)
I-410 (NB 1.92 mi, SB 2.00 mi, EB 13.36 mi, WB 11.75 mi)
Loop 1604 (EB 2.33 mi, WB 2.36 mi)
US 90 (EB 1.38 mi, WB 1.20 mi)
US 281 (NB 4.03 mi, SB 4.03 mi)

Where and When Delay Occurs

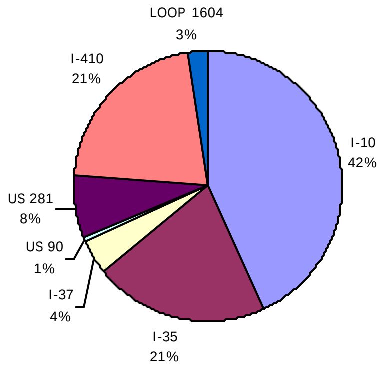


Exhibit I-3. Delay by Roadway

- I-10, the longest corridor, has more than 40% of the delay.
- I-35 and I-410 together have as much delay as I-10.

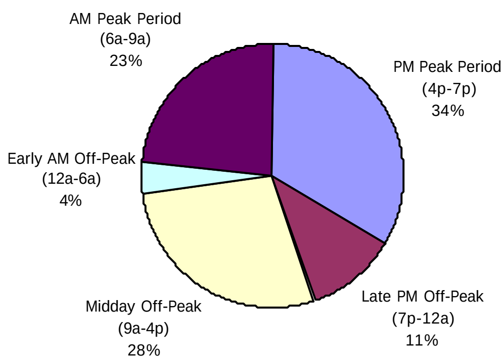


Exhibit I-4. Delay by Time of Day

- Evening delay is 50 percent greater than the morning peak.
- Midday delay is larger than the morning peak.

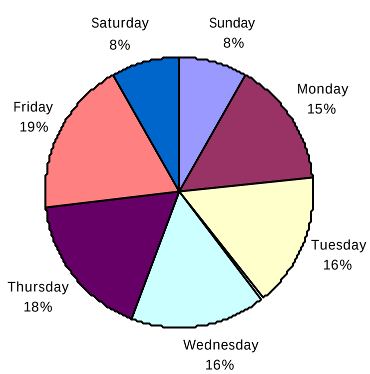
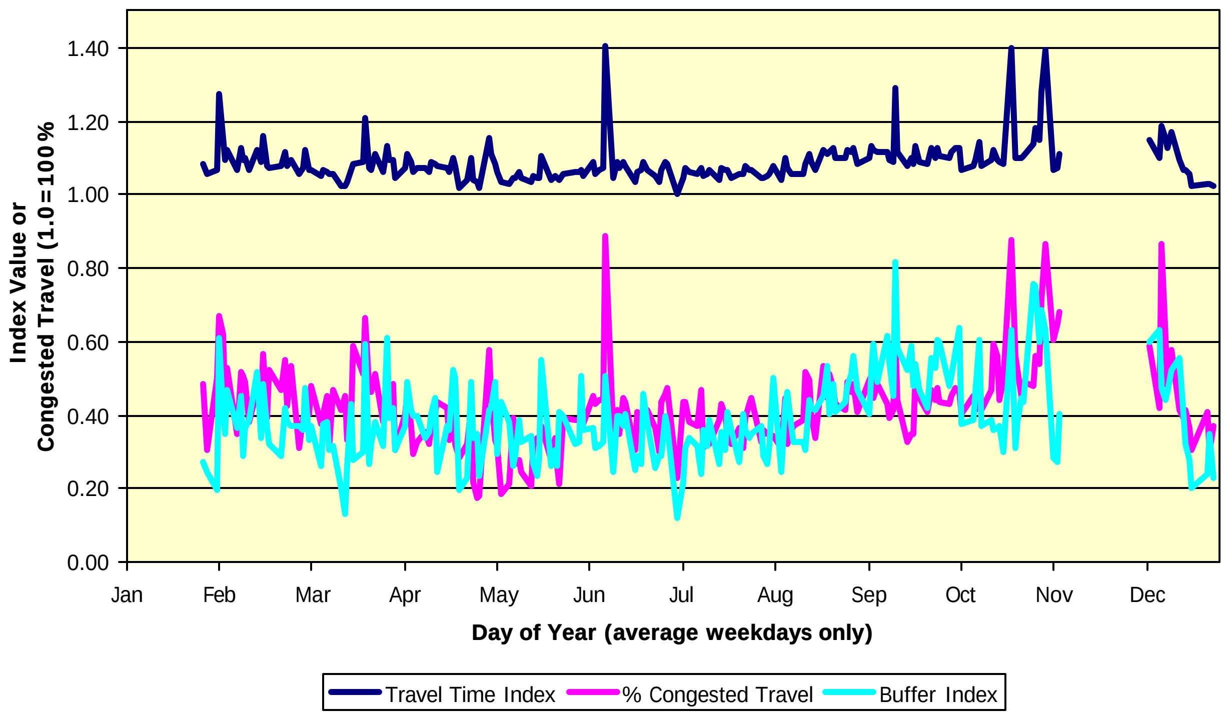


Exhibit I-5. Delay by Day of Week

- The weekend days combined have the delay of one weekday.
- Delay builds through the week to a Friday peak.



Note: Trend lines will be added to this graph when data from a sufficient time has been collected. Until multiple years of data are analyzed, the apparent trend may only be a seasonal variation in travel conditions.

Exhibit I-6. Mobility and Reliability Measures by Day of the Year

- There are three days with large congestion "spikes" and five days with unreliability spikes.
- Congestion and unreliability appear to be increasing over the last half of the year. This may be a trend, or it may be a seasonal variation.
- There were problems in January and November.

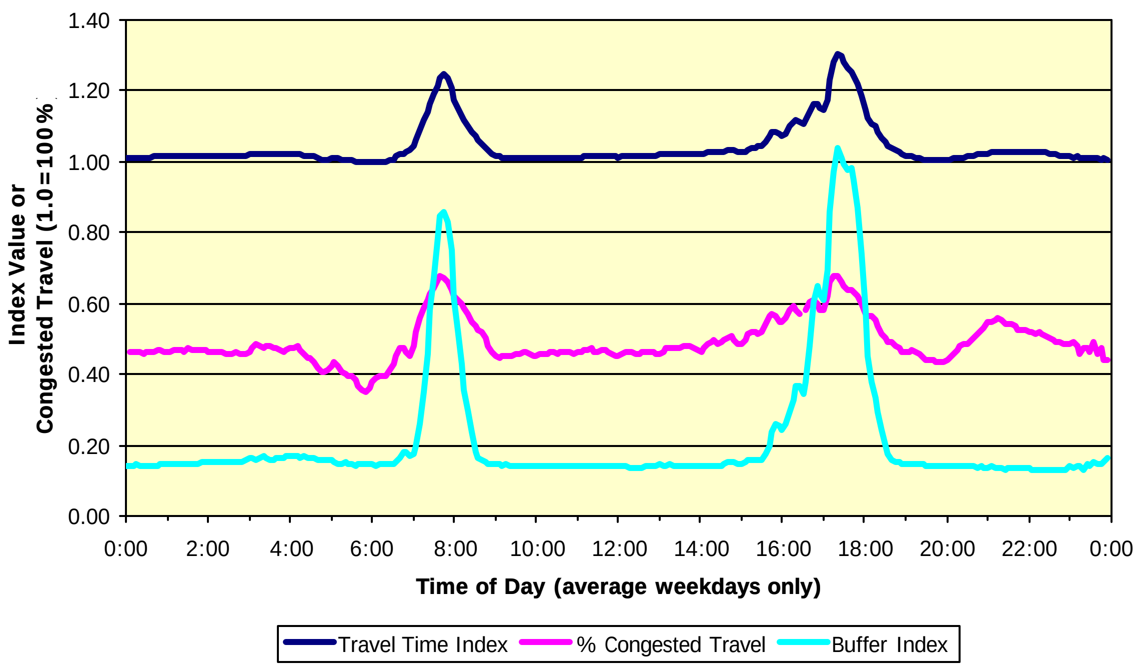


Exhibit I-7. Mobility and Reliability Measures by Time of an Average Day

- ♦ Congestion and unreliability follow about the same pattern.
- ♦ The morning and evening peaks are sharper than those seen in more congested cities.
- ♦ The evening peak is congested for a longer time than the morning.

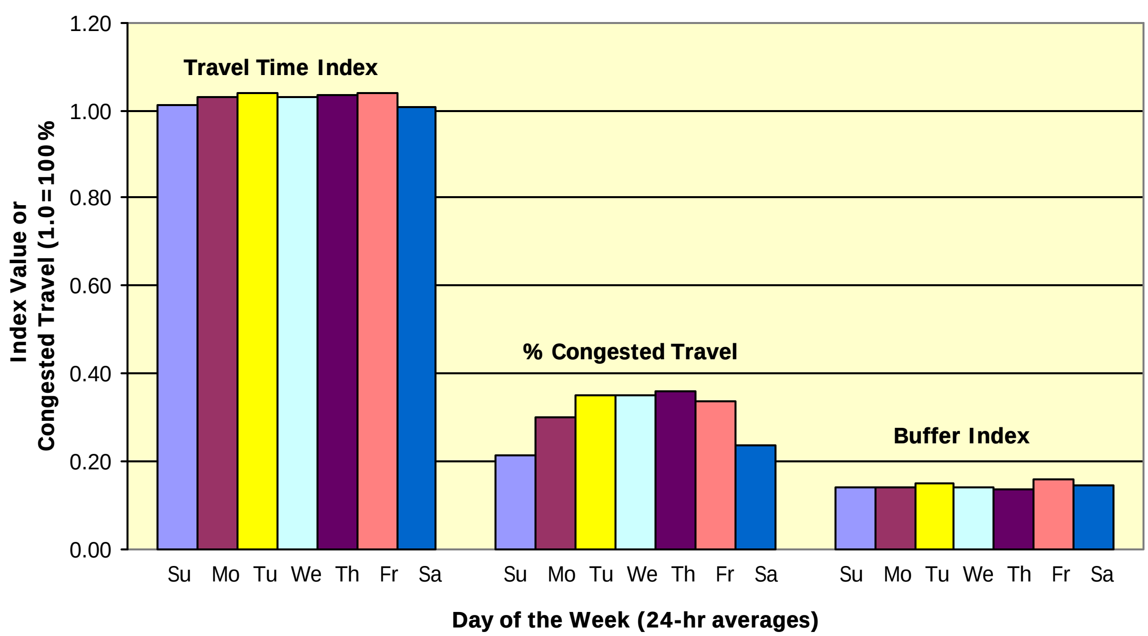


Exhibit I-8. Mobility and Reliability Measures by Day of an Average Week

- ♦ Congestion is worse during weekdays, but reliability is relatively consistent for all days.

2000 MOBILITY AND RELIABILITY REPORT—
BY DIRECTIONAL SECTION, SAN ANTONIO, TEXAS

Exhibit I-9. Top Ten List—Most Congested Peak Periods

Rank	Directional Section	Date	Time Period	Travel Time Index
1	US 281 NB	February 1, 2000	PM Peak Period	2.69
2	US 281 NB	November 3, 2000	PM Peak Period	2.61
3	US 281 NB	June 9, 2000	PM Peak Period	2.52
4	US 281 NB	September 14, 2000	PM Peak Period	2.51
5	US 281 NB	November 7, 2000	PM Peak Period	2.38
6	I-410 NB	August 31, 2000	AM Peak Period	2.29
7	I-410 EB	December 13, 2000	AM Peak Period	2.26
8	I-410 NB	March 21, 2000	AM Peak Period	2.20
9	I-37 NB	March 20, 2000	PM Peak Period	2.17
10	LP 1604 EB	June 9, 2000	PM Peak Period	2.14

Exhibit I-10. Top Ten List—Least Reliable Peak Periods

Rank	Directional Section	Date	Time Period	Buffer Index
1	LP 1604 EB	August 4, 2000	Midday Off-Peak	419%
2	US 281 SB	July 14, 2000	Midday Off-Peak	273%
3	LP 1604 WB	June 22, 2000	Early AM Off-Peak	267%
4	LP 1604 WB	May 15, 2000	PM Peak Period	252%
5	LP 1604 EB	August 28, 2000	PM Peak Period	240%
6	LP 1604 EB	September 18, 2000	AM Peak Period	235%
7	I-410 NB	May 25, 2000	AM Peak Period	234%
8	I-35 SB	October 30, 2000	AM Peak Period	227%
9	US 281 SB	February 24, 2000	PM Peak Period	219%
10	LP 1604 EB	April 4, 2000	PM Peak Period	217%

- US 281 NB has the most significant congestion peaks.
- Loop 1604, a relatively uncongested road, has several unreliable peaks, including a midday and an early morning period.
- Significantly congested and unreliable days are distributed throughout the year.
- The evening peak period has seven of the ten most congestion periods.

Exhibit I-11. Travel Time Index—San Antonio Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL							
I-37, NB (I-10/US 90 to I-35, 4.76 mi)	1.11	1.03	1.00	1.07	1.01	1.01	1.02
I-37, SB (I-35 to I-10/US 90, 4.54 mi)	1.00	1.00	1.00	1.03	1.01	1.00	1.01
US 281, NB (I-35 to Basse Rd, 4.03 mi)	1.15	1.12	1.07	1.82	1.45	1.14	1.28
US 281, SB (Basse Rd to I-35, 4.03 mi)	1.22	1.14	1.04	1.26	1.15	1.08	1.15
CENTRAL-SUBURBAN							
I-10, EB (Loop 1604 to Roland Ave, 21.01 mi)	1.29	1.14	1.01	1.26	1.14	1.06	1.14
I-10, WB (Gevers Ave to Loop 1604, 24.39 mi)	1.05	1.03	1.02	1.13	1.08	1.03	1.06
I-35, NB (I-10/US 90 to I-410, 18.09 mi)	1.27	1.17	1.05	1.24	1.15	1.09	1.16
I-35, SB (I-410 to I-10/US 90, 18.73 mi)	1.14	1.09	1.06	1.40	1.27	1.10	1.18
SUBURBAN							
US 90, EB (Zarzamora to I-35, 1.38 mi)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
US 90, WB (I-35 to Zarzamora, 1.20 mi)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
I-410, EB (Callaghan to I-35, 13.36 mi)	1.18	1.10	1.04	1.25	1.14	1.05	1.12
I-410, NB (Bandera to Callaghan, 1.92 mi)	1.67	1.26	1.01	1.15	1.06	1.04	1.14
I-410, SB (Callaghan to Bandera, 2.00 mi)	1.00	1.00	1.00	1.03	1.01	1.00	1.00
I-410, WB (I-35 to Callaghan, 11.75 mi)	1.08	1.04	1.01	1.19	1.09	1.02	1.06
LP 1604, EB (La Cantera Pkwy to Tradesmen, 2.33 mi)	1.02	1.01	1.00	1.44	1.10	1.01	1.04
LP 1604, WB (Lockhill-Selma to La Cantera Pkwy, 2.36 mi)	1.08	1.04	1.01	1.00	1.01	1.01	1.02
CORRIDOR AVERAGE	**1.14**	**1.07**	**1.03**	**1.19**	**1.10**	**1.04**	**1.08**

Note: These performance measures represent the portion (67.9 miles) of the total freeway system (211 miles) that contains ITS traffic monitoring sensors.

- The peak hour congestion values are much higher than the peak period values for US 281, Loop 1604, and I-410, indicating a short period of intense congestion.
- Several corridors have similar morning and evening period TTI values.
- I-410 and US 281 are the most congested corridors.

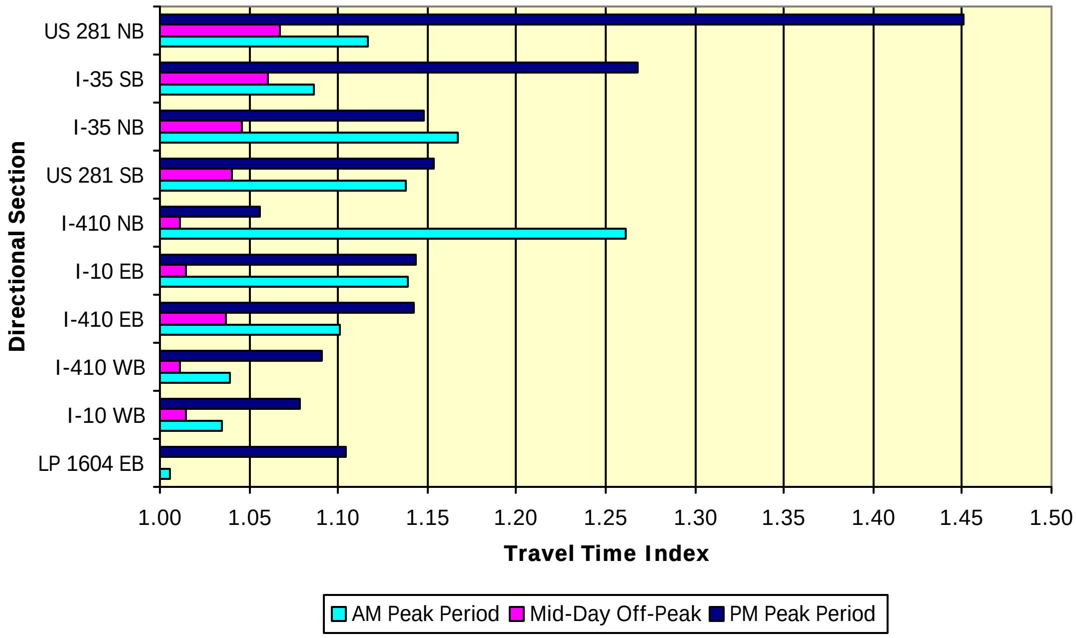


Exhibit I-12. Travel Time Index, by Ten Most Congested Directional Sections

Exhibit I-13. Buffer Index—San Antonio Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL							
I-37, NB (I-10/US 90 to I-35, 4.76 mi)	56%	20%	7%	9%	7%	9%	14%
I-37, SB (I-35 to I-10/US 90, 4.54 mi)	12%	12%	11%	21%	16%	12%	15%
US 281, NB (I-35 to Basse Rd, 4.03 mi)	28%	17%	16%	80%	96%	16%	60%
US 281, SB (Basse Rd to I-35, 4.03 mi)	64%	47%	12%	76%	46%	13%	47%
CENTRAL-SUBURBAN							
I-10, EB (Loop 1604 to Roland Ave, 21.01 mi)	103%	25%	13%	43%	9%	10%	25%
I-10, WB (Gevers Ave to Loop 1604, 24.39 mi)	21%	14%	12%	63%	37%	14%	27%
I-35, NB (I-10/US 90 to I-410, 18.09 mi)	83%	45%	13%	82%	45%	11%	45%
I-35, SB (I-410 to I-10/US 90, 18.73 mi)	46%	23%	12%	99%	84%	11%	58%
SUBURBAN							
US 90, EB (Zarzamora to I-35, 1.38 mi)	18%	7%	4%	4%	5%	6%	6%
US 90, WB (I-35 to Zarzamora, 1.20 mi)	6%	5%	5%	5%	5%	6%	5%
I-410, EB (Callaghan to I-35, 13.36 mi)	78%	46%	19%	111%	70%	28%	58%
I-410, NB (Bandera to Callaghan, 1.92 mi)	118%	120%	16%	79%	37%	25%	78%
I-410, SB (Callaghan to Bandera, 2.00 mi)	7%	8%	7%	31%	14%	8%	11%
I-410, WB (I-35 to Callaghan, 11.75 mi)	49%	25%	13%	107%	77%	18%	51%
LP 1604, EB (La Cantera Pkwy to Tradesmen, 2.33 mi)	41%	20%	13%	118%	109%	12%	62%
LP 1604, WB (Lockhill-Selma to La Cantera Pkwy, 2.36 mi)	37%	22%	16%	17%	14%	18%	17%
CORRIDOR AVERAGE	**56%**	**26%**	**10%**	**70%**	**52%**	**10%**	**32%**

Note: These performance measures represent the portion (67.9 miles) of the total freeway system (211 miles) that contains ITS traffic monitoring sensors.

- Evening reliability is a more significant problem everywhere except I-410 NB.
- US 281 and I-410 are the least reliable corridors.
- Loop 1604 has a significantly different Buffer Index for the two travel directions.
- US 281 and I-410 have sections with peak period unreliability values larger than the peak hour values.

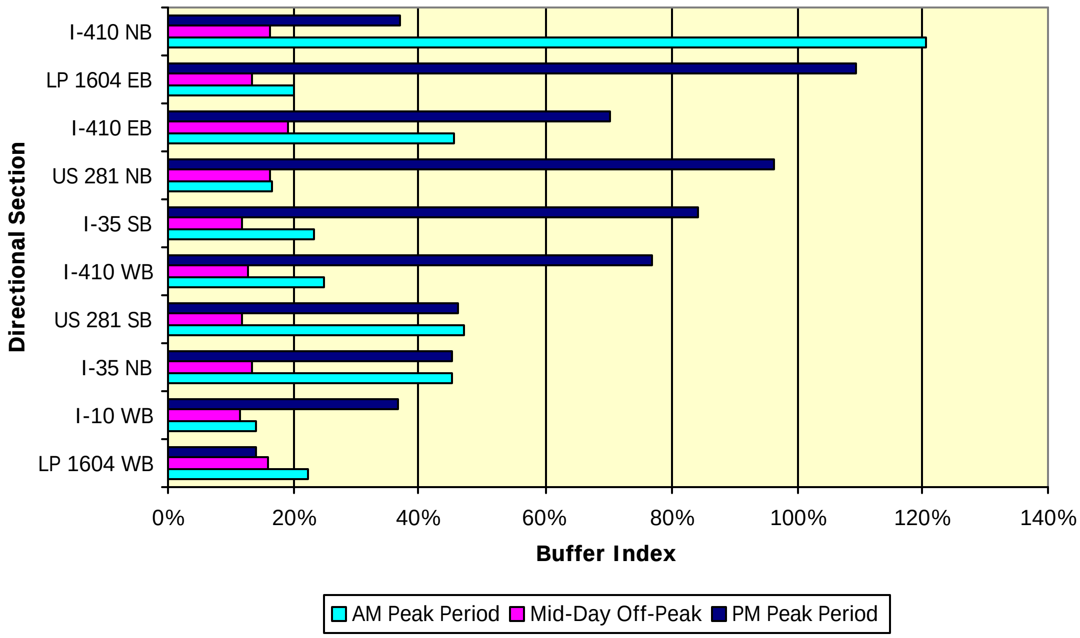


Exhibit I-14. Buffer Index, by Ten Least Reliable Directional Sections

Appendix J—Seattle, WA

2000 Regional Mobility and Reliability Data

A Supplement to:

Monitoring Urban Roadways: Using Archived Operations Data for Reliability and Mobility Measurement by Texas Transportation Institute and Cambridge Systematics, Inc., May 2001

Seattle, WA Findings

- The reliability measure values are some of the best in the 10 cities studied. This may indicate the effect of the operations improvements in the Seattle area.
- Morning and evening peaks each have 1/3 or more of daily delay.
- Weekend delay is about half of a normal weekday.
- Congestion and reliability are relatively consistent across the year.
- Reliability problems grow through the week.
- The morning peak congestion and reliability problems are slightly more intense, but do not last as long as the evening.
- Damage to the SR-520 Bridge in August 2000 caused congestion and unreliability to sharply increase.

Seattle, WA Data Source

- The Washington State Transportation Center (TRAC) under the direction of Mark Hallenbeck has been archiving Seattle freeway surveillance data for several years. The data are routinely produced on CDs each quarter and made available to requesters. An interface program is included that allows users to extract data of interest.
- TRAC has developed quality control procedures that flag erroneous or suspect data.
- Approximately 100 miles of the 240-mile freeway system is included in the archived data system. Data was provided by Washington State DOT. Significant data processing assistance and analysis advice was provided by the Washington State Transportation Center (TRAC) at the University of Washington.
- The data was collected primarily using single inductive loops. Speed estimates are calculated using local procedures. The data was reported by lane at 5-minute intervals.
- 100% of both the volume and speed data in the original data archive passed the initial quality control tests.
- The original data records included volume and speed for 83% of the time periods in 2000.
- 83% of the possible speed and volume records were found to be usable for further analysis.

Major Study Findings (Why you should read the Final Report)

- It is only 36 pages.
- Local data archiving occurs in some areas but easy accessibility and use of that data is much less widespread. Database management and analytical methods can be somewhat complex, and limited local resources and guidance have also hindered widespread development of easy-to-use data archives. Each area has essentially pursued their own development schedule and scope with funding from local sources. The report, and the associated best practices guide can assist agencies in the data archiving process.
- The mobility and reliability measures used in the report can most efficiently be used for local area trend analysis and analysis of important subjects at the national level. The data are less useful for city-to-city comparisons because of the incomplete ITS coverage and inconsistencies between cities. The report summarizes the measures used in the study and demonstrates how they can be prepared and interpreted.

Exhibit J-1. Trends in Mobility and Reliability Indicators

Indicator	2000	1999	Change
MOBILITY			
Travel Time Index	1.22		
Delay per Capita (hours)	3.8		
Percent Congested Travel	40%		
RELIABILITY			
Buffer Index	28%		
Misery Rate	25%		
Percent Variation	29%		

Notes: [1]These performance measures represent the portion (99.4 miles) of the total freeway system (240 miles) that contains ITS traffic monitoring sensors.
[2]All statistics reported in this exhibit are peak period averages for all weekdays in the year indicated (no holidays included).
[3]This exhibit will be used to illustrate annual trends once we have more than one year of data.

Data analysis by Texas Transportation Institute and Cambridge Systematics, Inc.
Data provided by Washington State DOT and the Washington State Transportation Center (TRAC) at the University of Washington.

Travel Time Index—A ratio of peak travel rate to a free-flow travel rate. A TTI of 1.3 indicates a 20-minute off-peak trip would take 26 minutes in the peak.
Delay per Capita—Estimate of the annual delay (in hours) per person in the urban area. Until a larger percentage of the system is instrumented, this value will be artificially low.
Percent Congested Travel—The percentage of vehicle-miles of travel that occur below 60 mph.
Buffer Index—The percentage of time above the average necessary to allow travelers to arrive on time for 95% of trips. The difference between the 95th and average travel rate divided by the average travel rate.
Misery Rate—The length of delay for the most congested 20% of the trips. The average travel rate is subtracted from the average rate for the slowest 20% of the trips. The Misery Rate is a percentage of extra time needed for the worst 20% of the trips.
Percent Variation—The amount of extra time needed to be on-time for 85% of the trips. Calculated as the standard deviation divided by the average travel rate.

An exhibit will be inserted here to illustrate annual trends once we have more than 1 year of data.

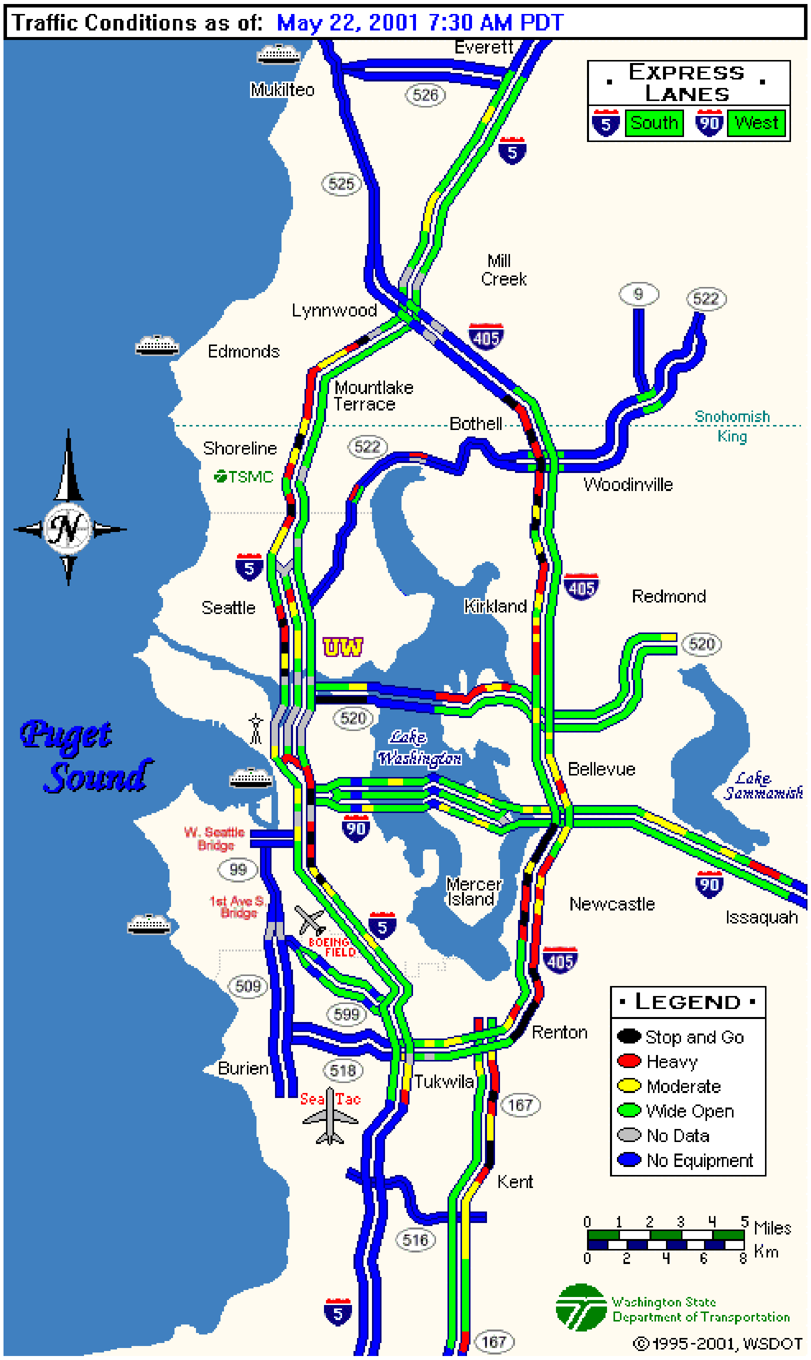


Exhibit J-2. Seattle, Washington Regional Area

(Source: Washington State DOT, http://www.wsdot.wa.gov/PugetSoundTraffic/)

Routes included in performance measure estimates:

I-5 (NB 35.42 mi, SB 35.42 mi)
I-90 (EB 13.99 mi, WB 13.99 mi)
I-405 (NB 28.49 mi, SB 28.49 mi)
SR 167 (NB 9.79 mi, SB 9.79 mi)
SR 520 (EB 11.73 mi, WB 11.73 mi)

Where and When Delay Occurs

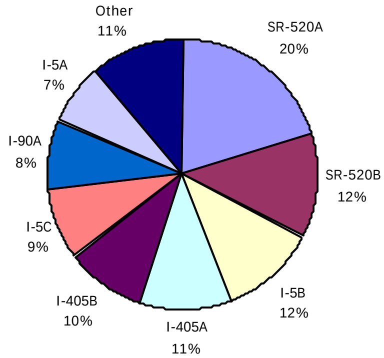


Exhibit J-3. Delay by Roadway

- ♦ SR 520 (32%) and I-5 (28%) have the most delay.
- ♦ SR 520A is one of the shortest segments but has 1/5 of the delay.

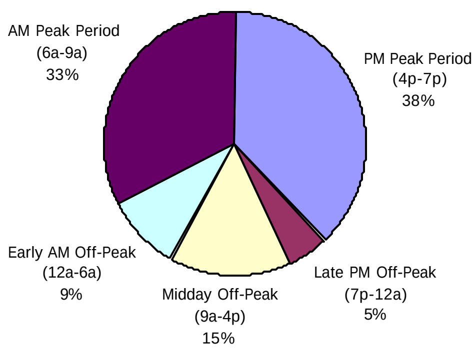


Exhibit J-4. Delay by Time of Day

- ♦ The evening peak period is almost 40% of the delay, slightly more than the morning.
- ♦ The off-peak delays are relatively modest, but total almost as much as the morning. This may be the effect of many vehicles traveling just under the 60 mph threshold.

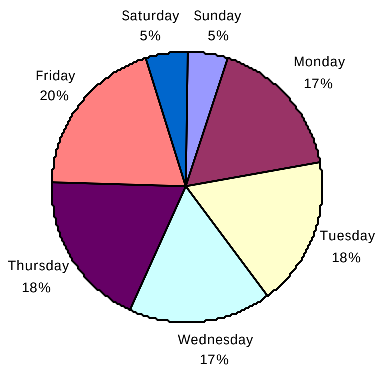
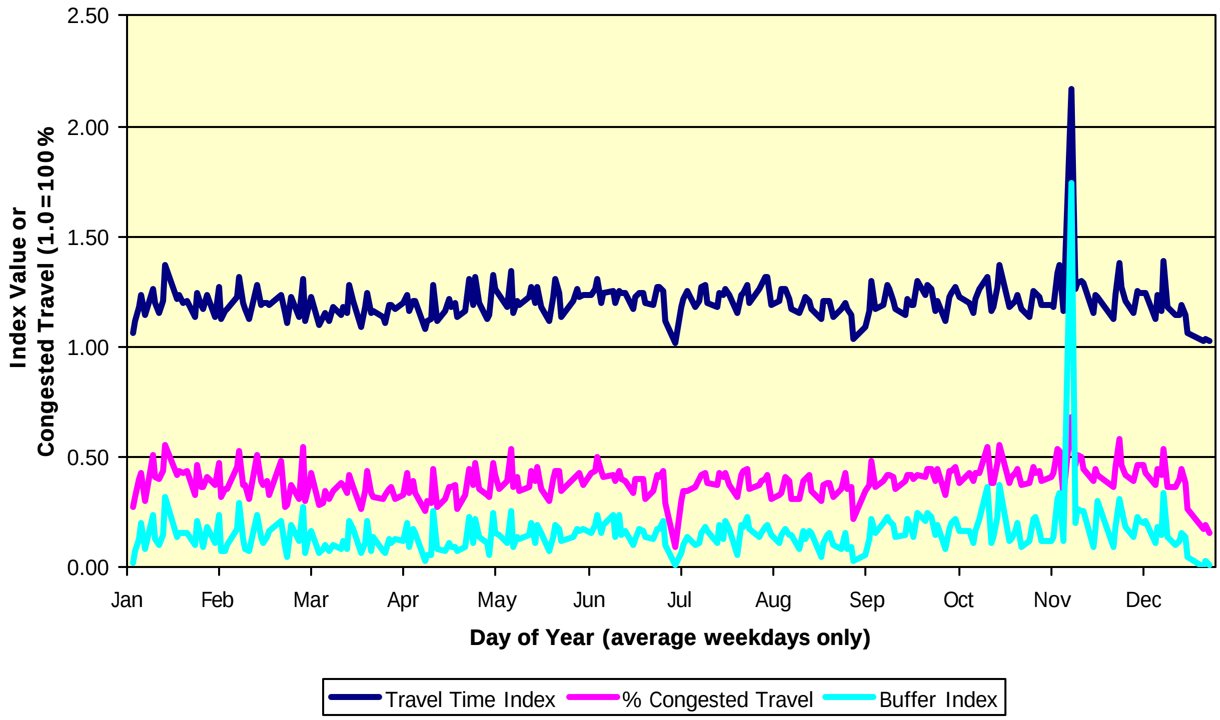


Exhibit J-5. Delay by Day of Week

- ♦ Delay peaks on Fridays.
- ♦ Weekend delay is not a significant problem relative to the weekdays.



Note: Trend lines will be added to this graph when data from a sufficient time has been collected. Until multiple years of data are analyzed, the apparent trend may only be a seasonal variation in travel conditions.

Exhibit J-6. Mobility and Reliability Measures by Day of the Year

- Congestion and reliability are relatively consistent across the year.
- A one-day spike in November may be a data collection or communication link problem.
- A few weekdays show very low congestion and good reliability levels.

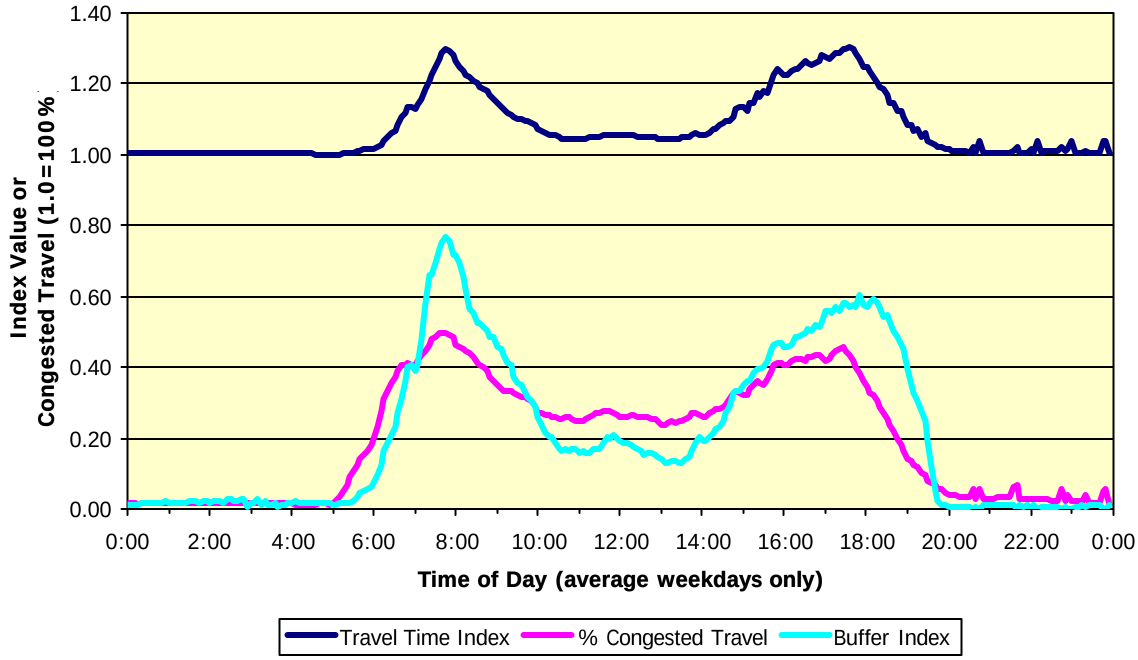


Exhibit J-7. Mobility and Reliability Measures by Time of an Average Day

- ♦ Congestion and reliability problems are a problem for a longer period in the evening.
- ♦ Midday levels are relatively low for all three indicators.
- ♦ Unreliability peaks at a higher level in the morning but the evening values are substantial as well.
- ♦ The single loop data collection devices, and the processing performed by TRAC produce statistics that meet the expected patterns. The TRAC procedures appear to make up for any deficiencies caused by the single loop system.

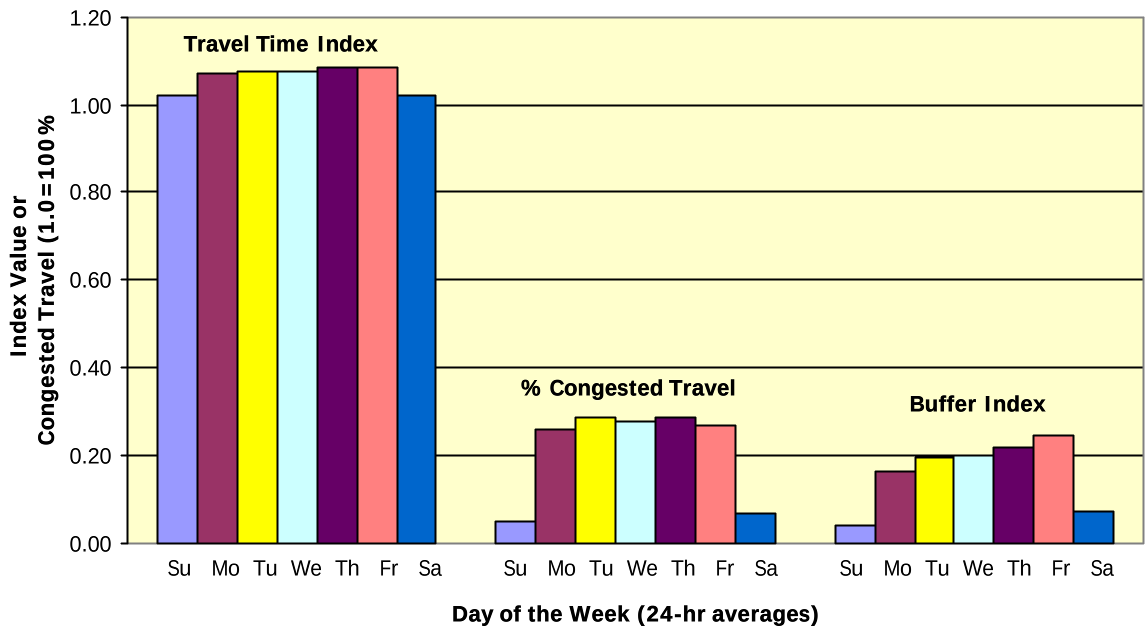


Exhibit J-8. Mobility and Reliability Measures by Day of an Average Week

- ♦ Congestion is similar for all weekdays.
- ♦ Reliability problems grow through the week.
- ♦ Weekend congestion and unreliability values are very low.

Exhibit J-9. Top Ten List—Most Congested Peak Periods

Rank	Directional Section	Date	Time Period	Travel Time Index
1	SR-520A EB	August 3, 2000	PM Peak Period	3.51
2	SR-520A EB	August 3, 2000	AM Peak Period	3.44
3	SR-520A EB	July 31, 2000	AM Peak Period	3.42
4	SR-520A EB	August 8, 2000	PM Peak Period	3.40
5	SR-520A EB	August 7, 2000	PM Peak Period	3.38
6	SR-520A EB	August 9, 2000	AM Peak Period	3.34
7	SR-520A EB	August 2, 2000	PM Peak Period	3.14
8	SR-520B WB	December 14, 2000	PM Peak Period	3.14
9	SR-520A EB	August 8, 2000	AM Peak Period	3.13
10	SR-520A EB	August 2, 2000	AM Peak Period	3.06

Exhibit J-10. Top Ten List—Least Reliable Peak Periods

Rank	Directional Section	Date	Time Period	Buffer Index
1	I-5A SB	January 7, 2000	PM Peak Period	230%
2	I-90A WB	October 4, 2000	AM Peak Period	181%
3	I-5A SB	November 22, 2000	PM Peak Period	171%
4	I-90A WB	July 20, 2000	AM Peak Period	170%
5	SR-520A EB	August 3, 2000	PM Peak Period	166%
6	SR-520A EB	August 7, 2000	PM Peak Period	166%
7	SR-520A EB	August 2, 2000	PM Peak Period	164%
8	SR-520A EB	August 8, 2000	PM Peak Period	163%
9	SR-520A EB	September 13, 2000	PM Peak Period	153%
10	SR-520A EB	April 27, 2000	PM Peak Period	150%

- These lists show the effect of the collision of a barge with a support column for the Evergreen Point Bridge over Lake Washington on Saturday, July 29, 2000. The collision closed one eastbound lane on SR-520, a freeway that is normally congested in both directions during both peaks. This also coincided with the Seafair Festival which features, among other elements, several overflights of I-90 by the Blue Angels—which cause the main reliever route for SR-520 to be closed in the midday period.
- More operational measures were implemented and free bus rides were given (10% increase in ridership) for the two-week repair time. Nevertheless, congestion and unreliability significantly increased on SR-520.

Exhibit J-11. Travel Time Index—Seattle Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL							
I-5B, NB (I-90 to SR-520, 3.72 mi)	1.30	1.23	1.16	1.35	1.27	1.16	1.25
I-5B, SB (SR-520 to I-90, 3.72 mi)	1.16	1.12	1.17	1.35	1.33	1.15	1.22
CENTRAL-SUBURBAN							
I-5A, NB (I-405 to I-90, 11.13 mi)	1.33	1.29	1.08	1.14	1.12	1.11	1.20
I-5A, SB (I-90 to I-405, 11.13 mi)	1.02	1.02	1.07	1.29	1.24	1.08	1.13
I-5C, NB (SR-420 to SR-526, 20.57 mi)	1.03	1.02	1.06	1.39	1.31	1.09	1.17
I-5C, SB (SR-526 to SR-520, 20.57 mi)	1.32	1.31	1.11	1.12	1.12	1.14	1.22
I-90A, EB (I-5 to I-405, 6.98 mi)	1.24	1.16	1.03	1.18	1.13	1.08	1.15
I-90A, WB (I-405 to I-5, 6.98 mi)	1.09	1.06	1.03	1.60	1.48	1.13	1.27
SR-520A, EB (I-5 to I-405, 4.43 mi)	2.20	2.00	1.16	1.43	1.37	1.34	1.69
SR-520A, WB (I-405 to I-5, 4.43 mi)	1.28	1.21	1.14	1.52	1.51	1.21	1.36
SUBURBAN							
I-405A, NB (I-5 South to I-90, 9.59 mi)	1.53	1.47	1.11	1.20	1.16	1.16	1.32
I-405A, SB (I-90 to I-5 South, 9.59 mi)	1.14	1.14	1.19	1.27	1.26	1.15	1.20
I-405B, NB (I-90 to I-5 North, 18.90 mi)	1.09	1.08	1.09	1.46	1.37	1.13	1.23
I-405B, SB (I-5 North to I-90, 18.90 mi)	1.30	1.26	1.09	1.30	1.26	1.14	1.26
I-90B, EB (I-405 to Issaquah, 7.01 mi)	1.00	1.00	1.01	1.04	1.03	1.02	1.02
I-90B, WB (Issaquah to I-405, 7.01 mi)	1.16	1.12	1.01	1.06	1.05	1.05	1.09
SR-167, NB (15th St to S. 23rd St, 9.79 mi)	1.17	1.18	1.06	1.04	1.03	1.08	1.11
SR-167, SB (S. 23rd St to 15th St, 9.79 mi)	1.02	1.02	1.11	1.40	1.31	1.12	1.17
SR-520B, EB (I-405 to Redmond Hwy, 7.30 mi)	1.08	1.07	1.10	1.49	1.38	1.13	1.22
SR-520B, WB (Redmond Hwy to I-405, 7.30 mi)	1.24	1.15	1.10	1.90	1.76	1.21	1.45
CORRIDOR AVERAGE	**1.21**	**1.19**	**1.09**	**1.28**	**1.24**	**1.12**	**1.22**

Note: These performance measures represent the portion (99.4 miles) of the total freeway system (240 miles) that contains ITS traffic monitoring sensors.

- Midday congestion levels are relatively low.
- The congested corridors show peak hour and peak period values that are relatively consistent; this indicates long periods of congestion.
- SR 520 has the highest average travel rate index values.

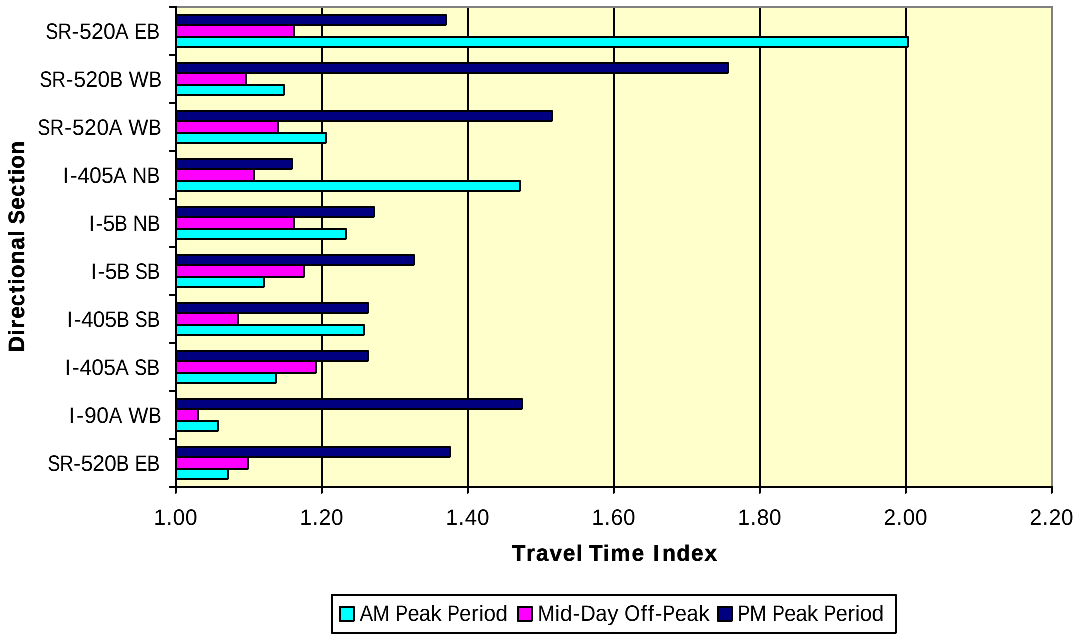


Exhibit J-12. Travel Time Index, by Ten Most Congested Directional Sections

Exhibit J-13. Buffer Index—Seattle Annual Summary, Year 2000

CORRIDOR	Morning Peak Hour (7a-8a)	Morning Peak Period (6a-9a)	Midday (9a-4p)	Afternoon Peak Hour (5p-6p)	Afternoon Peak Period (4p-7p)	Daily (24 hr)	Avg. Peak Period (am & pm)
CENTRAL							
I-5B, NB (I-90 to SR-520, 3.72 mi)	27%	28%	43%	41%	36%	29%	32%
I-5B, SB (SR-520 to I-90, 3.72 mi)	37%	32%	38%	37%	40%	27%	36%
CENTRAL-SUBURBAN							
I-5A, NB (I-405 to I-90, 11.13 mi)	34%	34%	24%	25%	27%	21%	30%
I-5A, SB (I-90 to I-405, 11.13 mi)	2%	2%	21%	41%	41%	17%	21%
I-5C, NB (SR-420 to SR-526, 20.57 mi)	7%	6%	18%	35%	37%	15%	21%
I-5C, SB (SR-526 to SR-520, 20.57 mi)	51%	49%	25%	28%	28%	25%	38%
I-90A, EB (I-5 to I-405, 6.98 mi)	40%	40%	1%	33%	32%	16%	36%
I-90A, WB (I-405 to I-5, 6.98 mi)	29%	22%	4%	50%	59%	18%	40%
SR-520A, EB (I-5 to I-405, 4.43 mi)	36%	47%	95%	81%	84%	56%	65%
SR-520A, WB (I-405 to I-5, 4.43 mi)	31%	34%	43%	31%	34%	33%	34%
SUBURBAN							
I-405A, NB (I-5 South to I-90, 9.59 mi)	36%	37%	18%	15%	14%	18%	26%
I-405A, SB (I-90 to I-5 South, 9.59 mi)	22%	22%	30%	27%	28%	21%	25%
I-405B, NB (I-90 to I-5 North, 18.90 mi)	6%	7%	24%	28%	29%	16%	18%
I-405B, SB (I-5 North to I-90, 18.90 mi)	24%	27%	18%	18%	21%	16%	24%
I-90B, EB (I-405 to Issaquah, 7.01 mi)	2%	1%	0%	6%	3%	1%	2%
I-90B, WB (Issaquah to I-405, 7.01 mi)	42%	33%	0%	13%	10%	10%	22%
SR-167, NB (15th St to S. 23rd St, 9.79 mi)	26%	27%	11%	6%	3%	11%	15%
SR-167, SB (S. 23rd St to 15th St, 9.79 mi)	3%	3%	23%	47%	48%	19%	26%
SR-520B, EB (I-405 to Redmond Hwy, 7.30 mi)	18%	17%	35%	34%	40%	23%	29%
SR-520B, WB (Redmond Hwy to I-405, 7.30 mi)	48%	50%	55%	46%	52%	47%	51%
CORRIDOR AVERAGE	**27%**	**26%**	**22%**	**29%**	**30%**	**19%**	**28%**

Note: These performance measures represent the portion (99.4 miles) of the total freeway system (240 miles) that contains ITS traffic monitoring sensors.

- SR-520 and one section of I-90 are the only corridors with Buffer Index values greater than 50%
- Some sections of I-5 also have reliability problems.
- I-90 has very low midday index values.

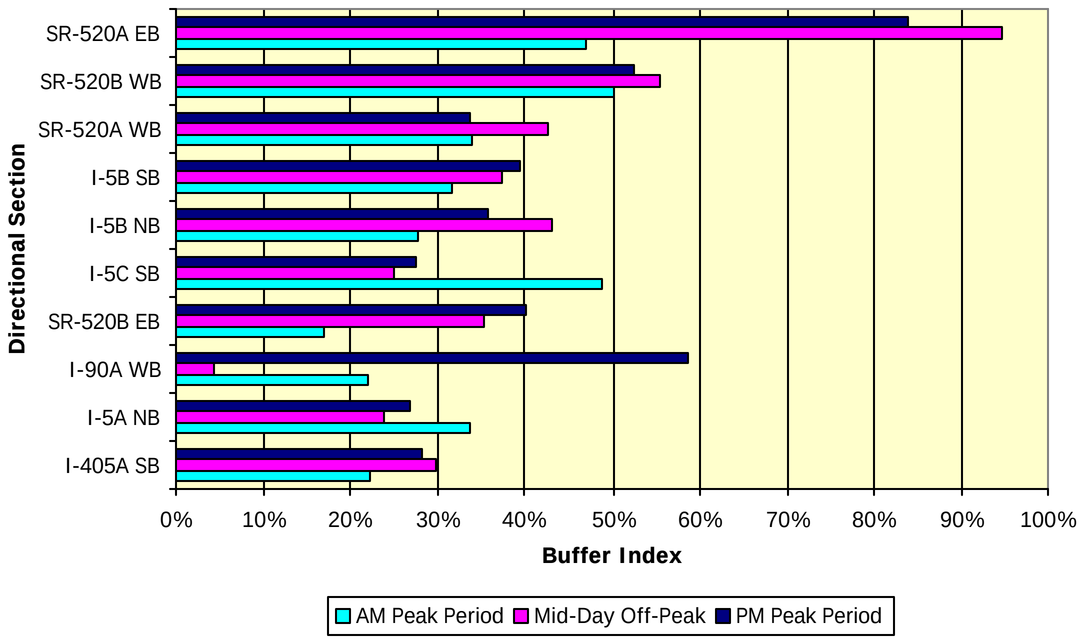


Exhibit J-14. Buffer Index, by Ten Least Reliable Directional Sections

To access an electronic version of this publication, visit:
http://mobility.tamu.edu/mmp

FHWA web address: http://ops.fhwa.dot.gov
Toll-Free "Help Line" 866-367-7487
Or you can send e-mail to: itshelp@fhwa.dot.gov

Publication No.: FHWA-OP-02-029