Final Report

LESSONS LEARNED: MONITORING HIGHWAY CONGESTION AND RELIABILITY USING ARCHIVED TRAFFIC DETECTOR DATA

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16. Abstract

This report summarizes the top 10 lessons learned from the Mobility Monitoring Program (http://mobility.tamu.edu/mmp) with respect to using archived traffic detector data for monitoring highway performance (e.g., traffic congestion and travel reliability). The Mobility Monitoring Program started in 2000 with archived freeway detector data from 10 cities. In 2004, the Program has grown to include nearly 30 cities with about 3,000 miles of freeway. In the first four years of the Program, the project team has gained valuable experience in the course of gathering archived data from State and local agencies for national congestion monitoring.

The top 10 lessons learned are centered on these three general areas: analytical methods, data quality, and institutional issues. We believe these lessons learned will be instructive to the Federal Highway Administration (FHWA) as they continue to develop a national congestion monitoring program, as well as being useful for State and local agencies engaged in developing congestion monitoring capabilities.

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- Numerous practitioners at State departments of transportation (DOTs), metropolitan planning organizations (MPOs), and other agencies who have provided us with archived data as well as insight into local issues and challenges.

1. INTRODUCTION

The Mobility Monitoring Program (http://mobility.tamu.edu/mmp) started in 2000 with archived freeway detector data from 10 cities. In 2004, the Program has grown to include nearly 30 cities with about 3,000 miles of freeway. In the first four years of the Program, the project team has gained valuable experience in the course of gathering archived data from State and local agencies for national congestion monitoring. The team has interacted with and had numerous informal conversations with transportation staff and managers in State departments of transportation (DOTs), metropolitan planning organizations (MPOs), and cities.

In this report, we have compiled lessons learned with respect to using archived traffic detector data for monitoring highway performance (e.g., traffic congestion and travel reliability). We believe these lessons learned will be instructive to the Federal Highway Administration (FHWA) as they continue to develop a national congestion monitoring program, as well as for State and local agencies engaged in developing congestion monitoring capabilities.

The top ten lessons learned are summarized here. More extensive discussions of each are included in this report, as well as an overview of current performance monitoring practices.

Analytical Methods

1. Don't wait for a "silver bullet."
2. Travel time modeling and estimation will always be necessary.
3. Visualize the data, pictures are cool!
4. Whatever affects traffic should be part of performance monitoring.

Data Quality

5. Use can improve quality.
6. Support for operations can be built with quality archives.
7. The devil is in the details.

Institutional Issues

8. Find and fix the barriers that hinder performance monitoring.
9. Performance monitoring may be a "killer app" for archived data.
10. Local knowledge contributes to national interpretation.

2. OVERVIEW OF CURRENT PRACTICE

2.1 The Performance Measurement Process in Transportation Agencies

Development and use of performance measures by the transportation profession has grown substantially in the past five years. At the Federal level, the requirements of the Government Performance Results Act of 1993 drove much of the initial activity at the U.S. DOT. At the same time, a general recognition of the importance of performance measurement and its potential for improving investments and policy actions grew independently at the Federal, State, and local levels. As a result, most transportation agencies have adopted – or are adopting – performance measurement as part of their routine processes. Several reasons can be noted for the use of performance measurement by transportation agencies:

- <u>Sound Business Practice.</u> The private sector has adopted performance measures as a way to better serve customers and assess return on investment. Transportation agencies have been moving in this direction also – a strong customer focus is now one of the primary stated goals of most agencies. Performance measurement is the mechanism by which progress toward this goal is assessed: "Know where you are before you decide where to go" is one way to describe this new direction. In addition, service-oriented measures increasingly being used in State and MPO Long Range Plans.
- <u>Use of Performance Measures Becoming More Widespread and Accepted as Best Practice within Transportation Agencies.</u> Performance measurement has been well established in pavement and bridge management for several years. Routine reporting of performance has become a powerful tool for showing progress and competing internally for funding. Other areas – such as congestion management, operations, and safety management – are finding that the use of performance measures by pavement and bridge management has "set the bar" for upper management review of programs and funding requests.
- <u>Accountability.</u> Transportation agencies are increasingly being asked by legislatures and executives for an assessment of how well problems are being addressed. The public is also more interested in "how are we doing?" kind of questions. Without the hard evidence provided by performance measures, transportation professionals are left with skimpy anecdotes that are insufficient at best and embarrassing at worst.
- <u>Performance Measurement is Becoming Easier To Do With New Technologies.</u> Performance measurement is based on the availability of the right kinds of data. As the deployment ITS technologies becomes more widespread, the data to undertake performance measurement becomes available.

2.2 Challenges in Establishing a Congestion Performance Monitoring Process

Several challenges still exist, however, before performance measurement by transportation agencies realizes its full potential. These challenges may be categorized around the steps involved in establishing a performance measurement process for congestion.

1. What metrics (measures) should be used?
2. What data are needed to support the metrics and how are they obtained?

3. How are performance measures presented internally and to decision-makers and the public?
4. How are performance measures used to make better investment decisions and to change policies and daily activities?

There has been a substantial amount of activity addressing what metrics should be used. (Section 2.4 discusses some the advances made in this area.) A significant challenge is in the area of data to support congestion performance measurement. Table 1 describes what challenges are created by these issues.

Table 1. Potential Challenges to Accurately Assessing Congestion

Issue	Why Is It a Problem?
Availability	Continuous streams of data are not readily available in many regions. The snapshot nature of data availability makes it difficult to analyze conditions during unique events or over time.
Coverage	Data is only available for a portion of the transportation network. Therefore, it is difficult to accurately assess the entire impacts of congestion.
Quality	Datasets often contain erroneous data or have gaps of missing data. The datasets need significant cleaning before they can be used. Accuracy may be compromised because of little or no calibration/validation.
Standards	Data is not consistently collected, analyzed, and stored across different regions, and often times within the same region. Standardization is needed to provide for the meaningful comparison of conditions in different regions.

Presentation of performance measures to various audiences is still an emerging field, but many agencies are nonetheless engaged in it. As agencies try different presentation methods (for example, "dashboards"), a consensus may be reached on the most effective methods. Graphs and exhibits are possibly the easiest method to convey performance measures. These might be stand-alone illustrations of measures or data that are not presented or addressed in other forms, or pictures that provide additional support to numerical presentations. Exhibits have been used to present a variety of concepts. The following are some that can be developed from the real-time traffic center data:

- Average number of days or peaks of "unacceptably bad" congestion;
- Relationship between traffic volume and travel time;
- Effect of major traffic incidents on volume and travel time in special circumstances;
- Time of day that congestion more frequently occurs;
- Maps of average speed by 30-minute time period; and
- Contour diagrams of travel speed along a roadway.

The final challenge – how to use performance measurement to guide activities – is a particularly daunting task. Put another way, how do we move beyond the simple reporting of performance and trends so that agencies' processes are affected?

2.3 Potential Uses of Performance Measures

Table 2 presents an overview of potential uses of freeway performance measures. As shown, a variety of transportation applications can make use of performance measures and significant overlap exists in the requirements of each application.

Table 2. Potential Uses of Congestion Performance Measures

Potential Uses of Performance Measures	Specific Applications	Requirements of Performance Measures
Roadway Operations – Real Time Applications	Incident Management	
	Traveler Information/ Diversion	Current and expected traffic states due to traffic flow breakdowns (travel time-based); throughput; diversion volumes
	Coordinated Freeway-Arterial Control	
	Weather Management	
	Special Event Management	
Roadway Operations – Operational Planning	Incident Management	Detail on detection, verification, on-scene, and response times
	Traveler Information/ Diversion	Trip- and corridor-based performance Effects of information content and timeliness
	Coordinated Freeway-Arterial Control	Effects of improved ramp and signal timing plans
	Evaluations of Operational Improvements	Consistent before/after measurements (travel time performance)
	Safety Countermeasures	Consistent before/after measurements (crash histories and profiles)
Transportation Planning	Travel demand forecasting	Ability to identify and rank deficiencies; inputs to assignment process; volumes and speeds for calibration
	Demand management	Trip- and corridor-based performance
	Air quality analysis	Inputs to emission models
	National Performance	Corridor-based and area-wide performance
	Congestion management	
	Truck travel estimation; parking utilization and facility planning; high-occupancy vehicles (HOV), paratransit, and multimodal demand estimation; congestion pricing policy	Trip- and corridor-based and area-wide performance
	Freight and Intermodal Planning	Trip- and corridor-based performance
Transportation Programming	Investment analysis; programmatic funding levels	Corridor-based and area-wide performance
Homeland Security	Evacuation Planning	Trip- and corridor-based performance
Transportation Research	Traffic flow model development	Highly detailed (time/space) performance measures
Emergency Response	Route planning	Trip- and corridor-based performance
Freight Carriers	Resource requirements	

2.4 State of the Practice in Monitoring Congestion Performance

2.4.1 Principles for Congestion Performance Monitoring

Table 3 presents several principles that would help guide the development of congestion performance monitoring programs.

Table 3. Principles for Congestion Performance Monitoring

Principle #	Principle
1	Mobility performance measures must be based on the measurement of travel time.
2	Multiple metrics should be used to report congestion performance.
3	Traditional HCM-based performance measures (V/C ratio and level of service) should not be ignored but should serve as supplementary, not primary measures of performance in most cases.
4	Both vehicle-based and person-based performance measures are useful and should be developed, depending on the application. Person-based measures provide a "mode-neutral" way of comparing alternatives.
5	Both mobility (outcome) and efficiency (output) performance measures are required for congestion performance monitoring. Efficiency measures should be chosen so that improvements in their values can be linked to positive changes in mobility measures.
6	Customer satisfaction measures should be included with quantitative mobility measures for monitoring congestion "outcomes".
7	Three dimensions of congestion should be tracked with congestion-related performance measures: source of congestion, temporal aspects, and spatial detail.
8	The measurement of reliability is a key aspect of roadway performance measurement and reliability metrics should be developed and applied. Use of continuous data is the best method for developing reliability metrics, but abbreviated methods should also be explored.

Foremost among these is the notion that ***congestion performance measures must be based on the measurement of travel time.*** Travel times are easily understood by practitioners and the public, and are applicable to both the user and facility perspectives of performance. Figure 1 shows how travel times can be developed from data, analytic methods, or a combination. Clearly, the best methods are based on direct measurement of travel times, either through probe vehicles or the more traditional "floating car" method. However, both of these have drawbacks: probe vehicles currently are not widely deployed and the floating car method suffers from extremely small samples. Further, since many performance measures require traffic volumes as well, additional collection effort is required to develop the full suite of performance measures. Use of ITS roadway equipment addresses these issues, but this equipment does not measure travel time directly; ITS spot speeds must be converted to travel times first. Other indirect methods of travel time estimation use traffic volumes as a basis, either those that are directly measured or developed with travel demand forecasting models.

Figure 1. Travel Time is the Basis for Defining Mobility-Based Performance Measures

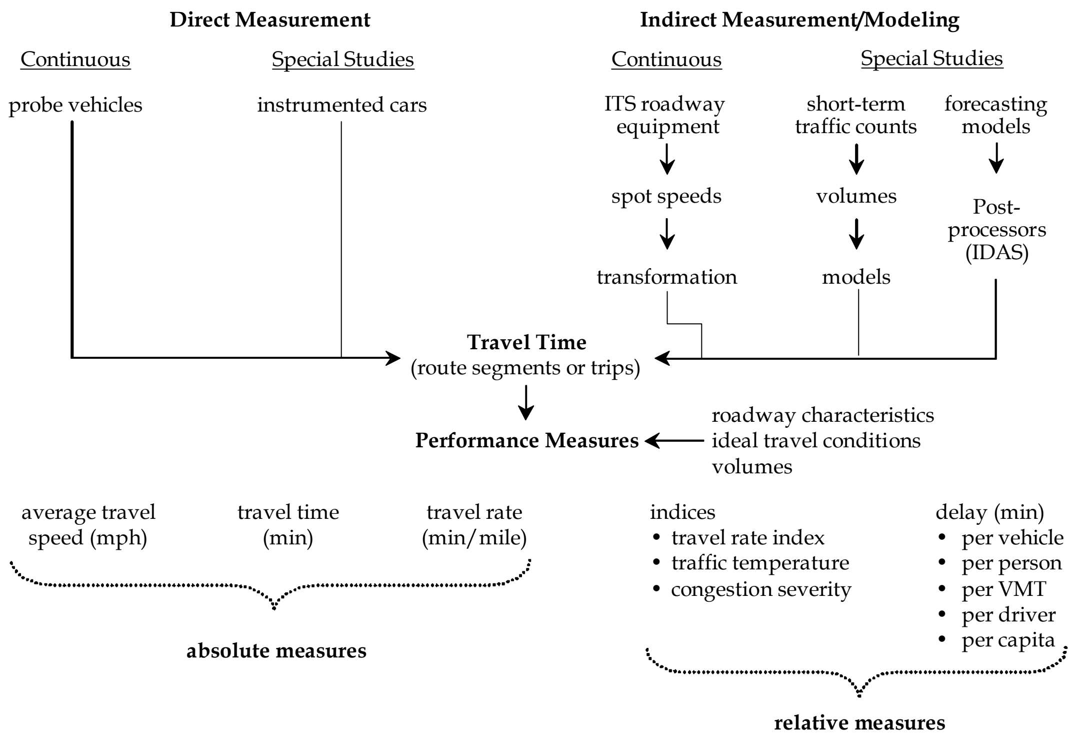


Figure 1 also shows how basic travel times can then be converted into a variety performance measures using a few fundamental prices of information about the environment where travel times were measured (roadway characteristics, "ideal" travel speeds, and traffic volumes). This implies that travel time-based performance measures are extremely similar in their basic nature, although some researchers have tended to exaggerate the differences. Travel time-based performance measures can be thought of as two types: 1) absolute measures, and 2) relative measures. Relative measures require comparison to some base conditions, usually "ideal" or "free flow" conditions.

Another principle highly relevant to the use of archived traffic data is the measurement of travel time reliability (usually referred to as just "reliability"). Travel time reliability is growing in significance and use in the transportation profession. The F-SHRP Reliability Research Program[1] defined reliability this way:

> "… from a practical standpoint, *travel time reliability can be defined in terms of how travel times vary over time* (e.g., hour-to-hour, day-to-day). This concept of variability can be extended to any other travel time-based metrics such as average speeds and delay. For the purpose of this study, travel time variability and reliability are used interchangeably."

[1] Future Strategic Highway Research Program (F-SHRP) reports, including the report on reliability, can be accessed at http://www4.trb.org/trb/newshrp.nsf/web/progress_reports?OpenDocument.

Because reliability is defined as the variability in travel times (or travel time-based metrics), measurement of reliability requires a distribution (i.e., a history) of congestion. The distribution can only be developed by using continuously collected data, such as those generated by ITS. The recently initiated NCHRP Project 7-15 (*Cost-Effective Measures and Planning Procedures for Travel Time Variation, Delay, and Reliability*) recognizes that complete data may not always be available for this purpose and is developing methods to estimate reliability from limited data.

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. Also, because reliability is directly related to the different sources of congestion, its measurement can provide insight into how much of an influence these events have on congestion. This insight can lead to crafting specific strategies for improving roadway performance.

2.4.2 Data for Congestion Performance Measurement

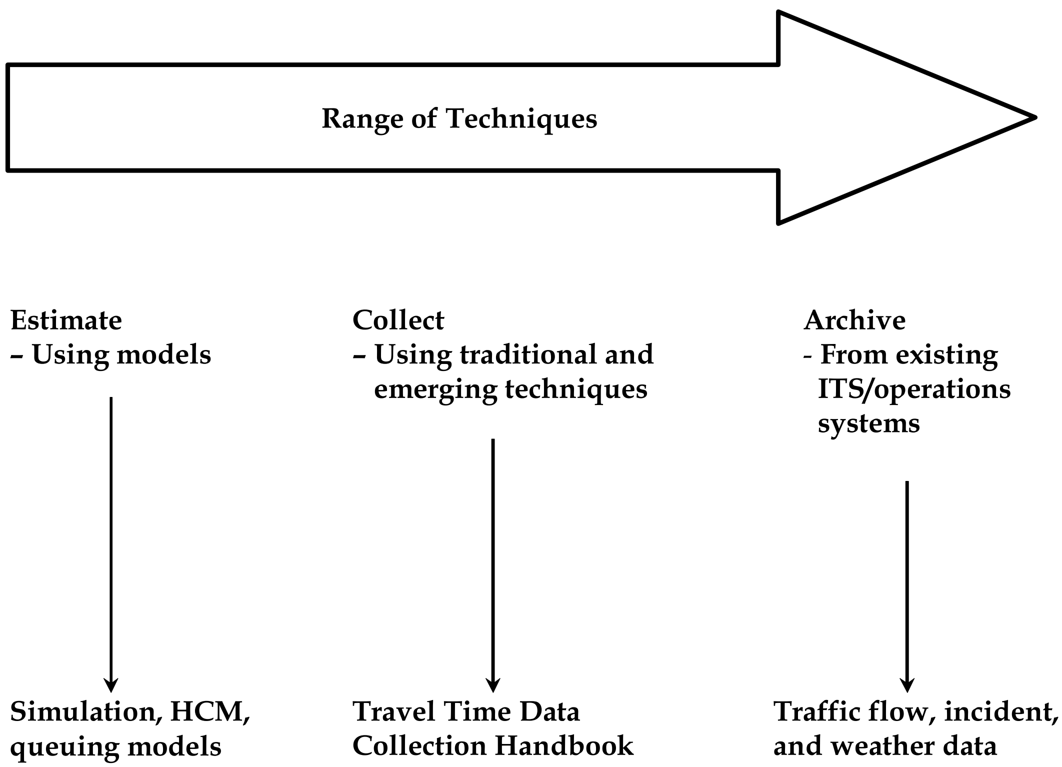
The use of congestion performance measures has been growing in recent years, and ranges from site-specific operations analysis to corridor-level alternative investments analysis and to area-wide planning and public information studies.

In the short term, some combination of surveillance data, planning data, and modeling must be used to support congestion performance measurement. Since surveillance coverage is not complete and data problems will cause gaps in existing coverage, other means must be used to fill in the freeway performance picture. However, the system performance data derived from surveillance data may be significantly different from other estimates or modeling efforts. Combining freeway surveillance 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.

As indicated in Figure 2, archived data from traffic operations systems currently is one of the most promising sources of data for freeway performance monitoring. This data source typically includes traffic volumes, spot speeds, and estimated or measured travel times. Archived operations data also can include causal information about freeway performance, such as traffic incidents and special events, work zones, or weather. When integrated, these archived data sources can provide significantly better performance information than the transportation profession has ever had. However, the research team recognizes that archived data sources are not perfect and do not represent the "silver bullet" of performance data. Several issues, such as accuracy, consistency, completeness, and coverage, must be addressed before archived data is a reliable source of performance information.

Even after equipment maintenance and quality assurance procedures are established, computer modeling or estimation techniques (left side of Figure 2) may be required for performance information. For example, the historical performance (e.g., what happened 15 minutes ago? one day ago? one month ago?) may indeed be largely and adequately measured by operations sensors on the roadway. How can transportation managers gauge the effects of alternative operating strategies without actually implementing them? How can planners determine the most effective transportation investments at the 20-year future time horizon? In these cases, freeway performance measures will have to be estimated or predicted using computer models or simulation. Similarly, manual data collection (e.g., special studies) may also be required. For example, vehicle occupancy (i.e., number of persons per vehicle) may be important data to have for measuring the performance of multimodal corridors. Vehicle occupancy, however, is not routinely collected by traffic operations as an essential data element; thus, additional data collection may be necessary.

Figure 2. Getting Performance Data



Source: *Measuring and Communicating the Effects of Traffic Incident Management Improvements,* NCHRP Research Results Digest Number 289, Transportation Research Board, May 2004.

For most cities, the data are collected at point locations using a variety of technologies, including single- and double-inductance loops, radar, passive acoustic, and video image processing. These technologies establish a small and fixed "zone of detection" and the measurements are taken as vehicles pass through this zone. 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:

- Data are collected by field sensors and accumulated in roadside controllers. These field measurements are by individual lane of traffic. At 20-second to two-minute intervals, the roadside controllers transmit the data to the traffic management center (TMC).

- Some areas perform quality control on original data, but this screening is typically simple and based on minimum and maximum value thresholds. These steps eliminate obviously incorrect data, but do not identify all of the problems.
- Areas that use single inductance loops as sensors can only directly measure traffic volume and lane occupancy. In these cases, algorithms are used to estimate speeds for the combinations of volume and occupancy. 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 one 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 reduce some of the storage burden and to satisfy outside requests for the data.

2.4.3 Congestion Performance Monitoring Programs Using Archived Traffic Detector Data

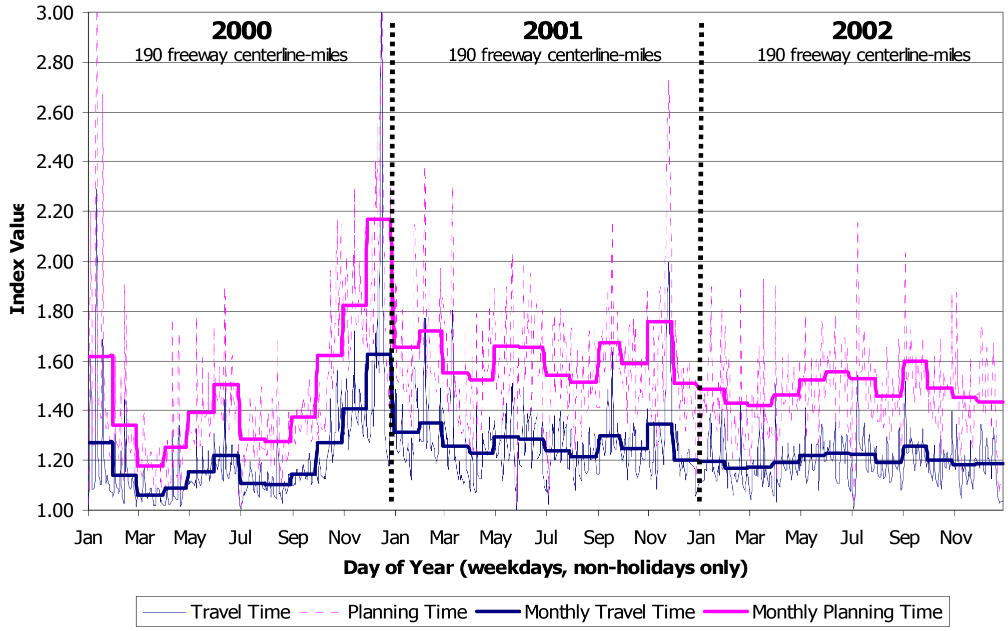
<u>National Programs</u>

Three programs currently monitor congestion performance trends nationally using archived traffic detector data. The first of these is the **Urban Congestion Report (UCR)** effort, which yields a monthly snapshot of roadway congestion in 10 urban areas and three national composite measures. UCR utilizes efficient, automated data collection procedures (colloquially known as "screen scraping" or "web mining") to obtain travel time directly from traveler information web sites and archives them at five-minute intervals on the weekdays when these services are available. Concurrent with the travel time data collection, other UCR acquisition programs obtain web-based data on weather conditions, traffic incidents, and work zone activity. The UCR produces monthly "snapshots" of congestion in the reporting cities. An example UCR snapshot is presented in Section 3 of this report.

The **Mobility Monitoring Program (MMP)** calculates system performance metrics based on data archived at traffic management centers (TMCs). These data are highly detailed measurements from roadway surveillance equipment installed for operational purposes; data from spot locations (volumes and speeds) are used as well as travel time estimates from probe vehicles (where available). For each participating city, the MMP develops congestion metrics at both the corridor and area levels; 23 cities participated in 2002 and 29 are reporting data for 2003. The concepts, performance measures, and data analysis techniques developed and used in the MMP are being considered for adoption and implementation by several State and local agencies. The MMP produces an annual report which presents a standard set of congestion graphics for each city; Figure 3 is one of the many graphics used.

The **Intelligent Transportation Infrastructure Program (ITIP)** is an ongoing program designed to enhance regional surveillance and traffic management capabilities in up to 21 metropolitan areas while developing an ability to measure operating performance and expanding traveler information through a public/private partnership involving the FHWA, participating State and local transportation agencies, and Mobility Technologies. Under this partnership, Mobility Technologies is responsible for deploying and maintaining traffic surveillance devices, and integrating data from these devices with existing traffic data to provide a source of consolidated real-time and archived data for the participating metropolitan areas. Deployment has been completed in Philadelphia, Pittsburgh, Chicago, and Providence, and is under way in Boston, Tampa, San Diego, Washington, DC, Phoenix, Los Angeles and San Francisco. Negotiations are currently active in 10 additional cities.

Figure 3. Congestion and Reliability Trends on Minneapolis-St. Paul Freeways, 2000-2002



Source: Mobility Monitoring Program, http://mobility.tamu.edu/mmp.

State and Local Activities

In addition to archiving ITS-generated data, many States and MPOs have embraced the concept of performance measurement. This trend is developed a substantial amount of inertia and can no longer be seen as theoretical – transportation agencies are imbedding performance measurement into their day-to-day activities. Examples include:

- **Arizona –** Both the Arizona Department of Transportation (ADOT) and the Maricopa Association of Governments (MAG) are supporting performance monitoring programs. ADOT has folded the implementation of a scaled down CMS (based on the MMP's reliability index) into the Arizona State transportation plan (MoveAZ Plan).

- **Minnesota –** The Minnesota Department of Transportation (MnDOT) is studying adoption of the primary performance measures in MMP, namely the travel time index as a mobility measure and the buffer time index as a reliability measure.

- **Oregon –** The Oregon Department of Transportation (ODOT) Traffic Management Section is studying several of the measures used in the MMP reports. The goal is to use the archived data in combination with other, more widely available data to construct a method to evaluate operations on the entire roadway network.

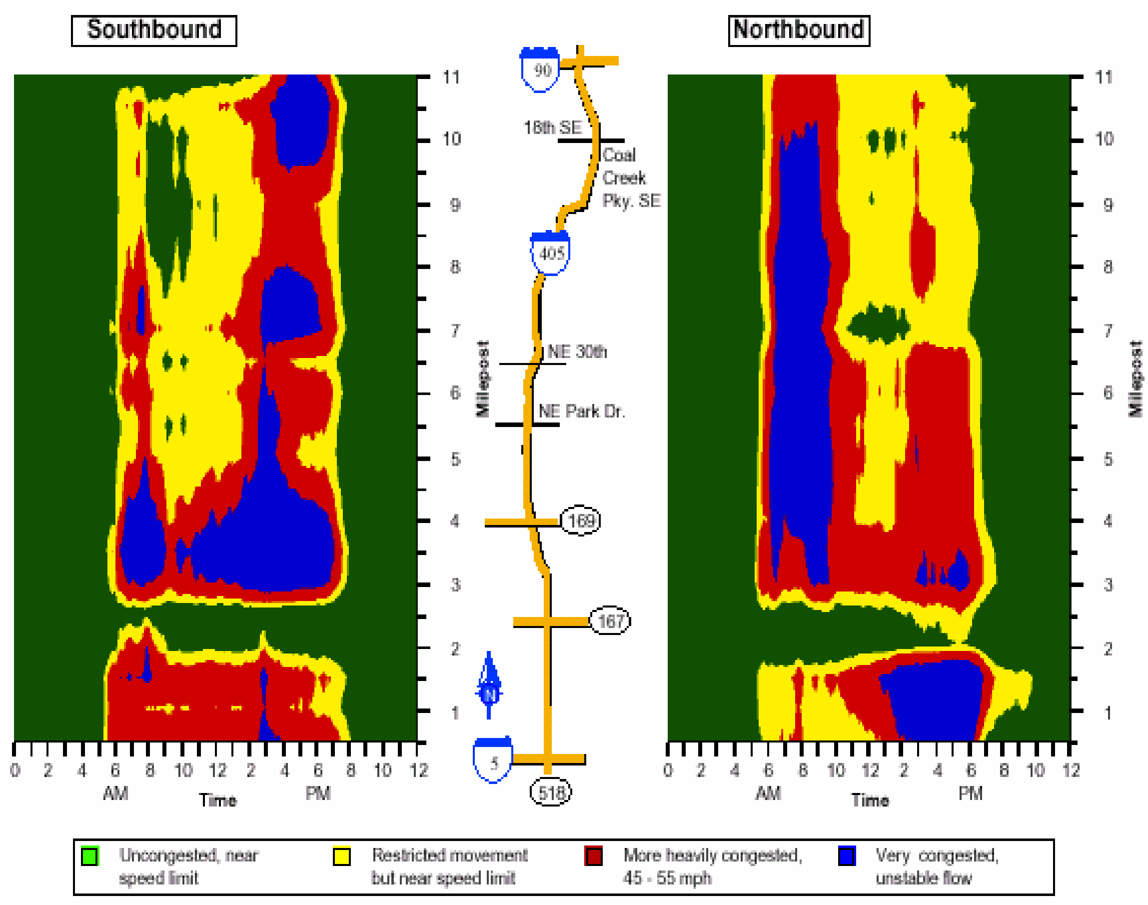
- **California –** The California Department of Transportation (Caltrans), with the technical support of the University of California-Berkeley, is in the process of developing and integrating a statewide data archive and performance monitoring system called PeMS (Freeway Performance Measurement System).

- **Virginia –** The University of Virginia and the Virginia Transportation Research Council (VTRC), the research arm of Virginia DOT, have been developing a statewide data archive managers for the Virginia DOT. Performance measurement is one of the many functions provided by the archive. Additionally, they have conducted several feasibility studies of the performance measures used in the MMP reports and are considering adoption of some of the mobility and reliability measures.

- **Michigan -** The Southeast Michigan Council of Governments (SEMCOG), the MPO for the Detroit region, is exploring the use of archived ITS data for performance monitoring.

- **Washington –** The Washington State DOT has a research and implementation effort to develop a set of mobility performance measures. The University of Washington, the primary analyst of archived data for WsDOT, is conducting the research and produces one of the premier annual congestion performance reports in the country. Figure 4 is one of the exemplary graphics from this report.

**Figure 4. Interstate 405 South Traffic Profile:
General Purposes Lanes, 1999 Weekday Average**



Source: Ishimaru, J.M., Nee, J. and Hallenbeck, M.E., *Central Puget Sound Freeway Network Usage and Performance, 1999 Update, Volume 1*, Washington State Transportation Center, Seattle, Washington, September 2000.

3. LESSONS LEARNED

Lesson 1: Don't wait for a "silver bullet."

All public agencies are required to make decisions based on limited or less-than-ideal information. Performance monitoring and the associated decisions stemming from transportation system performance should be viewed in this context. Some analysts believe that a wide gap remains between a multi-modal, system-wide performance measurement system and the available data to support it. Some agencies may be taking a "wait-and-see" attitude in regards to using archived data from traffic management centers. Or other agencies may be hoping that probe vehicle data from cell phones or vehicle monitoring systems will solve the data gap for performance monitoring. Some agencies may rely only on their data and not trust data collected by another agency. Yet numerous practitioners around the country have been using available data resources to make informed decisions about system performance.

The lesson learned is that transportation agencies should not wait idly for a "silver bullet" dataset or collection technique. More often, change in transportation is evolutionary rather than revolutionary, and agencies may find that what seemed like an ideal data source also has problems. Of course, agencies must become comfortable with available data resources and their features and limitations. In a limited number of instances, available data may be so poor as to not be considered for performance monitoring. Data of such poor quality should be obvious to even the casual observer.

The best practice appears to be using available data resources within an analysis framework that can eventually capture the benefits of improved or ideal data. An example of this practice comes from the Florida Department of Transportation (DOT). In their mobility performance measures program, the Florida DOT has designated the reliability of highway travel as a key mobility measure for their State highway system[2]. Ideally, a travel reliability measure would be formulated from a continuous (e.g., 24 hours a day, 365 days per year) data collection program over all highways. However, like most states, the Florida DOT does not have such a continuous data collection program, even in their major cities. Instead, they are planning to collect data for their reliability measure through a combination of archived data and additional floating car data collection.

Another advantage of embarking on a performance monitoring program even without the ideal data set is that agencies grow accustomed to reporting and using measures in their day-to-day management activities and decision-making. These functions are ultimately what performance measurement should be achieving. By starting now, agencies learn how to best use performance measure for their own uses.

[2] Florida DOT Mobility Performance Measures Program, http://www.dot.state.fl.us/planning/statistics/mobilitymeasures/default.htm, accessed June 1, 2004.

Lesson 2: Travel time modeling and estimation techniques will always be necessary.

Many performance monitoring programs rely on speed or travel time-based performance measures. As such, link travel time data form the basis for performance monitoring as well as numerous other advanced transportation applications (such as traveler information, dynamic routing, etc.). Because link travel time data is not readily available or cheaply collected for most highway links, many performance monitoring programs have relied on speed/travel time modeling and estimation techniques.

Some analysts have suggested or implied that if one cannot directly measure link travel times, then travel time-based performance measures are not feasible.[3] Other analysts predict a future in which link travel times will be ubiquitous and travel time modeling or estimation will be unnecessary. The inherent nature of a performance-based planning process requires that travel time-based performance measures are estimated for future planning scenarios. The lesson learned is that travel time modeling and estimation techniques will always be necessary (even with widespread availability of collected link travel times), particularly in a performance-based planning process. One of the challenges will be to ensure that estimation techniques produce roughly compatible travel time estimates as those from direct measurement.

[3] For performance monitoring, the key consideration for any method that estimates travel times (rather than measuring them directly) is that the method be internally consistent and not show bias. Therefore, even if the estimated travel times do not match observed ones, monitoring their change will still result in useful trend information. Further, if the direction and size of the error is known, adjustments can be made.

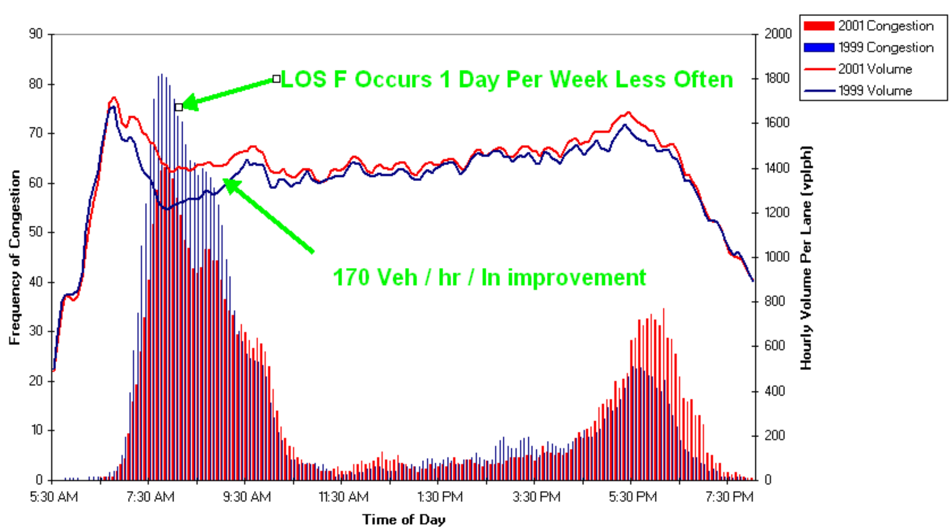
Lesson 3: Visualize the data, pictures are cool!

The audience for transportation performance information can include a wide range of transportation practitioners, agency mid- and upper-level managers, elected officials, business leaders, and the media. The lesson learned is that simple charts and graphics are more easily interpreted by this diverse audience than complex data tables and lengthy text descriptions. Data collectors and analysts may be adept at interpreting complex technical data because that is their primary job function; however, other non-technical audiences may only be able to devote 30 to 60 seconds to understanding key report elements.

Several practitioners have mentioned the "spouse test," in which they asked their spouse (who has a non-technical background) to review and interpret certain graphics or charts that illustrated transportation performance. Another "rule-of-thumb" comes from Mark Hallenbeck of the Washington State Transportation Center, who has remarked that every research project or activity should be summarized with a single page of text and a picture/graphic. Other practitioners have described themselves as disciples of Edward Tufte, who has written several award-winning books on displaying technical information in meaningful ways.[4]

The Washington State DOT is an agency that firmly believes in the power of graphical illustrations in performance monitoring. The DOT publishes an agency performance report every three months that is full of charts that demonstrate their progress on various goals and programs.[5] Additionally, Figure 5 contains a graphical illustration that shows improvements from ramp metering in Seattle.

Figure 5. Graphic Illustrating Improvements from Ramp Metering in Seattle



Source: Hallenbeck, M., *Data Collection, Archiving and Performance Measures: Why Should Freeway Operations Care?*, http://www.nawgits.com/icdn/data_for_freeway_ops.html, accessed Oct. 22. 2004.

[4] For more information, see http://www.edwardtufte.com/tufte/.
[5] Washington State DOT. *Measures, Markers, and Mileposts*. Accessed at http://www.wsdot.wa.gov/accountability/default.htm, June 2, 2004.

Lesson 4: Whatever affects traffic should be part of performance monitoring.

In the past, many public agencies have struggled to collect credible data about transportation system performance. Traffic management centers are beginning to help fill the data gap for performance monitoring; however, many agencies still have inadequate resources to consider collecting data other than speeds or travel times that are directly related to system performance. A few agencies, however, have recognized that there are numerous activities and events (some beyond their agency's control) that affect system performance. Thus, despite their best efforts and significant resource expenditure, some agencies may see a decline in the measured system performance.

<u>The lesson learned is that, to be effective, performance monitoring must also gather information on activities and events that can affect system performance</u>. Examples include:

- System usage;
- Traffic incidents;
- Work zones;
- Severe or inclement weather;
- Special events;
- Economic conditions; and,
- Data quality.

By tracking these influential factors, performance monitoring programs could better target why performance changes at certain times and what solutions are most appropriate. The data can also be used to demonstrate the benefits of operations strategies.

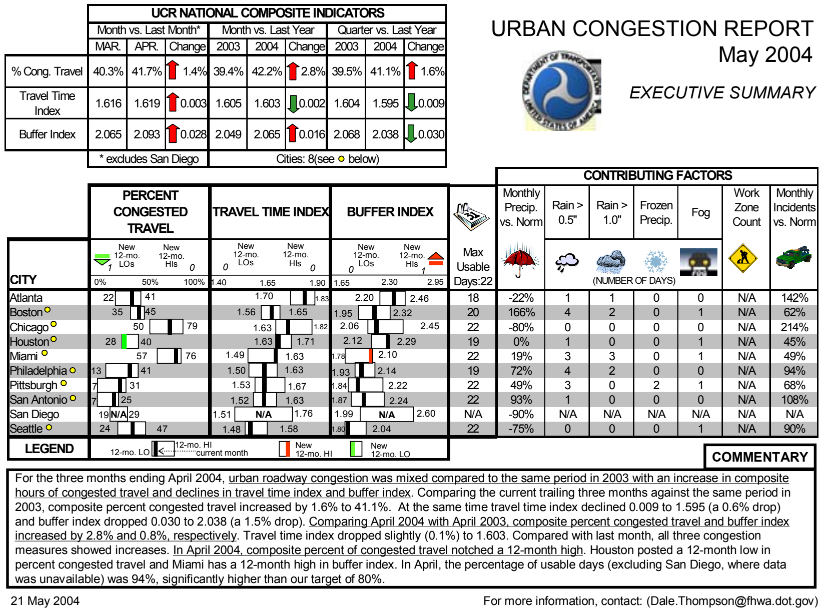
As an example, the Urban Congestion Reporting (UCR) Program performed by Mitretek for the FHWA reports several mobility and reliability performance measures on a monthly basis. The performance reports include these contributing factors (see Figure 6):

- Data quality (number of usable days of data);
- Monthly precipitation compared to normal;
- Number of days with bad weather (low visibility, heavy or freezing precipitation); and
- Monthly incident rate compared to normal;

Performance reports in FHWA's Intelligent Transportation Infrastructure Program (ITIP) provide another example of reporting transportation performance in the context of possible explanatory measures. In addition to several mobility and reliability performance measures, the following are included (see Table 4):

- System usage (peak period and total vehicle-miles of travel [VMT]);
- Number of bad weather days (significant rainfall, freezing precipitation, or low visibility);
- Total number of traffic incidents reported; and
- Data quality (completeness, validity, and coverage of archived traffic data).

Figure 6. Monthly Summary from FHWA's Urban Congestion Report



URBAN CONGESTION REPORT
May 2004
EXECUTIVE SUMMARY

UCR NATIONAL COMPOSITE INDICATORS	Month vs. Last Month*			Month vs. Last Year			Quarter vs. Last Year		
	MAR.	APR.	Change	2003	2004	Change	2003	2004	Change
% Cong. Travel	40.3%	41.7%	↑ 1.4%	39.4%	42.2%	↑ 2.8%	39.5%	41.1%	↑ 1.6%
Travel Time Index	1.616	1.619	↑ 0.003	1.605	1.603	↓ 0.002	1.604	1.595	↓ 0.009
Buffer Index	2.065	2.093	↑ 0.028	2.049	2.065	↑ 0.016	2.068	2.038	↓ 0.030
	* excludes San Diego			Cities: 8(see ○ below)					

CITY	PERCENT CONGESTED TRAVEL (New 12-mo. LOs 1, New 12-mo. HIs 0; 0% – 50% – 100%)	TRAVEL TIME INDEX (New 12-mo. LOs 0, New 12-mo. HIs 0; 1.40 – 1.65 – 1.90)	BUFFER INDEX (New 12-mo. LOs 0, New 12-mo. HIs 1; 1.65 – 2.30 – 2.95)	Max Usable Days:22	Monthly Precip. vs. Norm	Rain > 0.5"	Rain > 1.0"	Frozen Precip.	Fog	Work Zone Count	Monthly Incidents vs. Norm
Atlanta	22 – 41	1.70 – 1.83	2.20 – 2.46	18	-22%	1	1	0	0	N/A	142%
Boston ○	35 – 45	1.56 – 1.65	1.95 – 2.32	20	166%	4	2	0	1	N/A	62%
Chicago ○	50 – 79	1.63 – 1.82	2.06 – 2.45	22	-80%	0	0	0	0	N/A	214%
Houston ○	28 – 40	1.63 – 1.71	2.12 – 2.29	19	0%	1	0	0	1	N/A	45%
Miami ○	57 – 76	1.49 – 1.63	1.78 – 2.10	22	19%	3	3	0	1	N/A	49%
Philadelphia ○	13 – 41	1.50 – 1.63	1.93 – 2.14	19	72%	4	2	0	0	N/A	94%
Pittsburgh ○	7 – 31	1.53 – 1.67	1.84 – 2.22	22	49%	3	0	2	1	N/A	68%
San Antonio ○	7 – 25	1.52 – 1.63	1.87 – 2.24	22	93%	1	0	0	0	N/A	108%
San Diego	19 N/A 29	1.51 N/A 1.76	1.99 N/A 2.60	N/A	-90%	N/A	N/A	N/A	N/A	N/A	N/A
Seattle ○	24 – 47	1.48 – 1.58	1.80 – 2.04	22	-75%	0	0	0	1	N/A	90%

CONTRIBUTING FACTORS: Rain > 0.5", Rain > 1.0", Frozen Precip., Fog (NUMBER OF DAYS)

LEGEND: 12-mo. LO, 12-mo. HI, current month; New 12-mo. HI; New 12-mo. LO

COMMENTARY

For the three months ending April 2004, urban roadway congestion was mixed compared to the same period in 2003 with an increase in composite hours of congested travel and declines in travel time index and buffer index. Comparing the current trailing three months against the same period in 2003, composite percent congested travel increased by 1.6% to 41.1%. At the same time travel time index declined 0.009 to 1.595 (a 0.6% drop) and buffer index dropped 0.030 to 2.038 (a 1.5% drop). Comparing April 2004 with April 2003, composite percent congested travel and buffer index increased by 2.8% and 0.8%, respectively. Travel time index dropped slightly (0.1%) to 1.603. Compared with last month, all three congestion measures showed increases. In April 2004, composite percent of congested travel notched a 12-month high. Houston posted a 12-month low in percent congested travel and Miami has a 12-month high in buffer index. In April, the percentage of usable days (excluding San Diego, where data was unavailable) was 94%, significantly higher than our target of 80%.

21 May 2004 — For more information, contact: (Dale.Thompson@fhwa.dot.gov)

Source: Mitretek Systems, Urban Congestion Reporting Program.

Table 4. Excerpt from ITIP Performance Report for Providence, Rhode Island

PROVIDENCE – JULY 2004: MONTHLY FREEWAY PERFORMANCE REPORT
Current Performance and Trends

Measures	Current Month	Average for most recent 3 months		Comparison to same 3 months last year	
	July 2004	May 2004 to Jul 2004	Short-Term Trend	May 2003 to Jul 2003	Long-Term Trend
Performance Measures					
Travel Time Index	1.11	1.12	-1% ↓	n.a.	n.a.
Buffer Index	27%	28%	-1% ↓	n.a.	n.a.
% Congested Travel	49%	48%	+1% ↑	n.a.	n.a.
Total Delay (veh-hours) per 1000 VMT	1.48	1.53	-3% ↓	n.a.	n.a.
Explanatory Measures					
Peak Period VMT (000)	48,324	48,471	0% —	n.a.	n.a.
Monthly VMT (000)	173,037	169,241	+2% ↑	n.a.	n.a.
Bad Weather Days	3	2	+50% ↑	n.a.	n.a.
Total Incidents	194	215	-10% ↓	n.a.	n.a.
Data Quality Measures					
% complete	93%	95%	-2% ↓	n.a.	n.a.
% valid	95%	95%	0% —	n.a.	n.a.
% of VMT covered	53%	52%	+1% ↑	n.a.	n.a.
% of freeway miles	34%	34%	0% —	n.a.	n.a.

Source: Mobility Technologies, Inc., Intelligent Transportation Infrastructure Program

Lesson 5: Use can improve quality.

A vested interest in data collection is one of the best motivators for quality data. Poor data quality can sometimes result when data collectors are physically or institutionally distant from the data users. A common example of this situation is State agencies collecting data to meet Federal reporting requirements. Another example could be a division within a State DOT charged with collecting data of primary interest to another division or department within the State DOT. A vested interest occurs when the data collectors are also data users or are directly affected by decisions made with the data they collect. To the extent that this can be created, data quality will improve when.

There are numerous instances in which a data user has dealt with poor quality data collected by another agency or another division within the same agency. The first response is typically notifying the data collectors of such problems, since in many cases the data collectors may not be aware of certain quality problems since they do not use the data. After the quality problems are repeatedly obvious, the next response is typically encouragement or requirement to meet some data quality criteria. This response may yield some improvement, but some agencies may "game" the system or "post-process" data to meet certain quality checks without inherently improving the data collection process.

<u>The lesson learned is that, in these instances, the agency or workgroup collecting data should be encouraged to use the data to improve their own agency functions or decision-making</u>. An example of this practice comes from the Highway Performance Monitoring System (HPMS), in which the State DOTs report various highway and travel data to the Federal Highway Administration. Originally developed in 1978, the HPMS and its reporting requirements were seen by some State DOTs as simply another requirement that did not result in usable data for their own agency. As a result, the quality of HPMS data in its early years suffered in some states. In the 1990s, many State DOTs began to integrate the HPMS data collection into their own data programs, and began to supplement their own agency analyses with data collected for HPMS. The net result has been more scrutiny of the HPMS data by State DOTs, with fewer concerns about data quality.

Another example comes from the use of archived traffic detector data. In some cities, users of the archived data were lamenting its poor quality for their particular application. A typical response was to let the traffic operations center know about the poor data quality. In some instances, this may have resulted in some improvements to quality. However, many traffic operations centers have become more interested in improving detector data quality because they want to use the archived data to perform additional functions within their workgroup (such as performance monitoring, ramp metering, and travel time or traveler information. As more traffic operations centers use archived data for new and more sophisticated applications, greater attention will be paid to data quality. Such applications include the posting of estimated travel times on dynamic message signs and performance monitoring.

Lesson 6: Support for operations can be built with quality archives.

Public agencies typically struggle with their budgets. As a result, many transportation operations divisions have to justify their expenditures on operations and management activities or risk having their budget cut or diverted to other programs. The lesson learned here is that data collected and archived while managing the transportation system can be easily reformulated to demonstrate the benefits of operations and management activities. However, the reuse of operations data for analytical purposes requires at least two things: 1) foresight to develop information systems that support real-time traffic management activities as well as historical analyses; and 2) commitment to collect and maintain quality data that can be used to demonstrate the benefits of operations. Such processes have long been in place in DOTs in the form asset management systems such as those for pavement and bridge management. Operations must compete for resources internally with these interests who are usually better equipped with "hard" information about system conditions and expected benefits. Archived operations data can help to "level the playing field".

Anecdotal evidence from several states points to cases where the value of operations activities was questioned by State legislators or upper-level managers within a State DOT.[6,7] For example, an operations manager from Minnesota DOT highlighted the importance of accurate data in maintaining political support for the agency's incident response team. Members of the State legislature were questioning the value of the freeway service patrol, suggesting that the State agency could not afford to change commuters' tires and give away free gas. However, with their archived data, the Minnesota DOT was able to show that the freeway service patrol was the initial detection source for about 20 percent of incidents that blocked State highways. Based on their quick access to this data, the Minnesota DOT was able to respond to the legislators. In fact, the DOT is now looking for innovative ways to expand their freeway service patrol with their new-found support. The DOT manager attributed this to their ability to access and analyze quality archived data.

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[6] Several of the anecdotes were discussed at a USDOT/ITS America Data Quality Workshop in April 2004, summary available at http://www.nawgits.com/icdn/dq_workshop.html, accessed June 2, 2004.

[7] Hallenbeck, M., *Data Collection, Archiving and Performance Measures: Why Should Freeway Operations Care*? http://www.nawgits.com/icdn/data_for_freeway_ops.html, accessed Oct. 22. 2004.

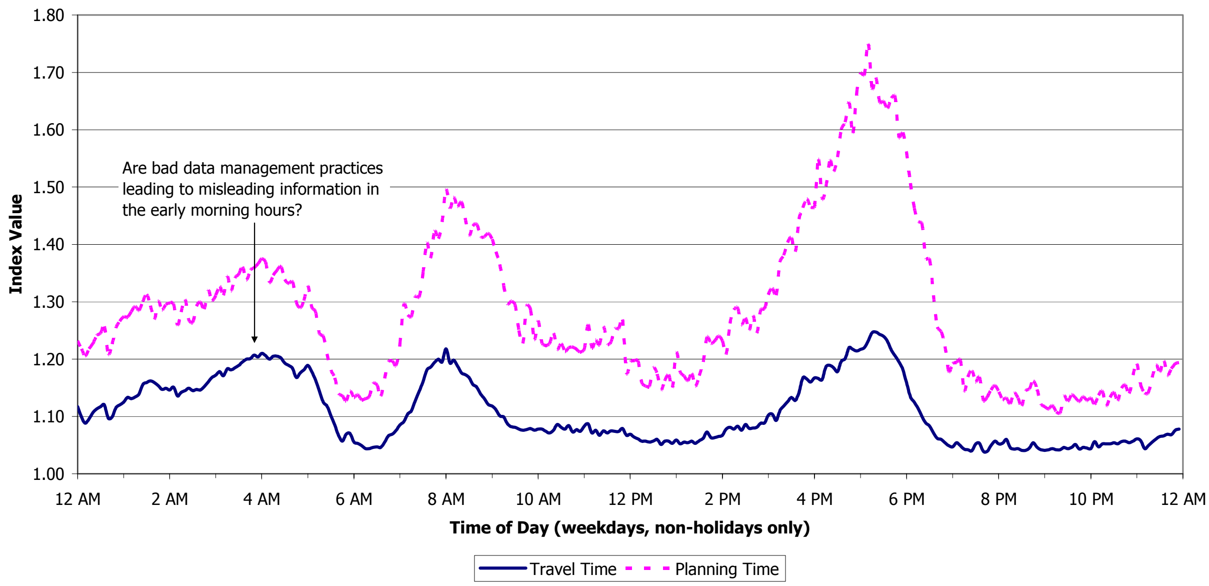
Lesson 7: The devil is in the details.

Over the past three years, the Mobility Monitoring Program team has gathered archived traffic detector data from more than twenty different agencies. In doing this, they have encountered a wide variety of data management and archiving practices. Some of the data management practices could be described as sloppy and produce misleading or inaccurate data for performance monitoring applications. Some data collection and management practices are simply not documented well enough, leading to confusion or uncertainty during data analysis.

The lesson learned is that the devil is in the details; that is, there are several seemingly minor data management practices that could have significant consequences when using archived data for performance monitoring. Several real examples follow:

- When does zero really mean zero? Most traffic detector systems report zero values for volume, occupancy, and speed when no vehicles are detected during the reporting period. This can be a common occurrence if the reporting period is short (1 minute or less) and the road has low traffic (during early morning hours). However, some data archives average these zero speeds (which are really missing or null speeds) with other measured speeds when summarizing data for permanent storage. For example, a speed of 60 mph is averaged with a speed of 0 mph (no traffic) to get an incorrect average of 30 mph. The result of this practice is that several cities appear to have slow speeds and congestion in the early morning hours (see Figure 7).

Figure 7. Illustration of Common Phenomenon: Slow Speeds During Early Morning Hours



- In other cases, traffic detector systems report zero values as error codes (for various hardware or software failures). Thus, the data analyst is typically unable to determine if the data is missing because of a detector malfunction, or simply because there was light traffic and no vehicles were detected during the reporting period.

- How many samples in summary statistics? Several data archives summarize detailed traffic detector data before storing permanently in their data archive. For example, the data archive may retrieve 1-minute data samples but only store 5-minute summary statistics. Problems arise when the data archive does not record how many data samples were actually used in the calculation of summary statistics. Assume that we have 1-minute data samples, but an intermittent communication failure prevented the collection of 3 of the 5 possible minutes of data. When the 2 available 1-minute data samples are aggregated into the 5-minute summary statistics, the volume subtotals will be inaccurate because 3 of the 1-minute samples are not available. Analysts will not be aware of this inaccurate subtotal unless metadata is kept to record the number of data samples used in calculating summary statistics. The result of this practice is that detectors may appear to be undercounting, and system-wide vehicle-miles of travel (VMT) estimates from these detector systems may also appear to be lower than normal.

Lesson 8: Find and fix the barriers that hinder performance monitoring.

Some of the barriers to the development of archived data systems are similar to those experienced in further developing transportation operations and management functions:

- Lack of financial resources for building and maintaining systems;
- Professional capacity to manage and analyze large data archives and warehouses;
- Widely ranging costs and benefits of implementation; and
- Uncertainty about data quality.

<u>It will be vitally important to identify and remove these and other barriers to performance monitoring.</u>

Lack of funding will always be a potential barrier in public agencies. Generally, though, if a product or idea makes intuitive sense and provides clear benefits, funding becomes less of an issue. In some cases, funding for data archiving systems has not been readily available because no agency was seen as a true beneficiary or data-hungry user. Or there was no application for archived data of such low quality. In a few instances, funding for data archiving systems became a non-issue when the benefits and applications of the archived data were clearly defined and desired by several agencies.

The professional capacity to manage large databases is not universal in the traffic management industry, although a few states and regions have managed to custom-build powerful and user-friendly data warehouses. The problem is more prevalent in smaller areas where the skill sets and staff time are not available to build data warehouses, and limited commercial off-the-shelf products force agencies to pay for custom database solutions. There are numerous lessons to be learned about data warehousing from other industries (like banking, retail sales, etc), as well as from the few good examples of data warehouses already built for traffic detector data.

Uncertainty about data quality has stalled or hindered efforts at using archived data in several cities. In some instances, the data quality may be acceptable but unfamiliarity with the data and how it is collected and managed causes uncertainty. In other cases, uncertainty about data quality is based on bad experiences with trying to salvage poor quality data for certain planning applications. FHWA has initiated several data quality activities that attempt to address this barrier to using archived data systems. For example, FHWA has defined several standardized measures of traffic data quality and are producing guidelines for how to implement data quality assessment procedures.[8] Two other white papers on traffic data quality were also prepared for regional workshops to discuss data quality issues.[9]

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[8] *Defining and Measuring Traffic Data Quality*, EDL # 13767, available at http://www.its.dot.gov/itsweb/welcome.htm. Guidelines for traffic data quality programs will be available from FHWA in Fall 2004.

[9] *Advances in Traffic Data Collection and Management*, EDL # 13766, and *State of the Practice for Traffic Data Quality*, EDL # 13768, both available at http://www.its.dot.gov/itsweb/welcome.htm.

Lesson 9: Performance monitoring may be a "killer app" for archived data.

Traffic managers are, by the very nature of their work, most interested in real-time data on current traffic conditions and events. The "champions" for formalizing data archiving in the National ITS Architecture in the mid-1990s were mostly planners, researchers, and other data-hungry analysts. In some cases, traffic managers supported minimalist data archives but were seldom data users. In even fewer instances, traffic managers were champions for developing data archives. However, traffic managers may be in the best position to champion and implement data archiving systems: they collect the data, they maintain the equipment, and they are most familiar with data collection devices and protocol. The only thing that seemed to be missing was a tangible benefit or application for traffic managers to assume responsibility for developing and maintaining data archives.

Current trends and anecdotal evidence indicate that more traffic managers have taken an interest in developing and maintaining data archives. There appear to be at least two applications that provide tangible benefits to traffic managers:

- Performance monitoring – helps traffic managers preserve or expand funding for operations; and
- Detector status/health reporting – helps traffic managers diagnose and troubleshoot extensive data collection systems.

<u>Of these two applications, performance monitoring appears to be the most compelling application that is likely to strengthen traffic managers' interest in developing data archiving systems</u>. Short-term traffic forecasting procedures that use historical traffic patterns in their algorithms are another application that could potentially push the need for better data and more functional archives. However, the eventual adoption of such methods by operators is not known at this time.

Lesson 10: Local knowledge contributes to national interpretation.

The FHWA and US DOT are responsible for reporting their performance in meeting agency goals, one of which is related to mobility and highway congestion. The source of data for this performance reporting (as well as most US DOT data programs) is State and local agencies. Thus, FHWA relies on these State and local agencies to provide data in a standard format (such as in the Highway Performance Monitoring System). Alternative data sources for national performance monitoring currently being explored include archived traffic detector data and traveler information data, which are not typically provided in a standard format by State or local agencies. The end result, standard format or not, is that in many cases the gathered data is not sufficient by itself to explain and interpret various trends in system performance. Local knowledge from State or local agencies is often required to interpret trends or better understand changes or relationships in system performance.

The lesson learned is that capturing local knowledge is desirable for interpreting system performance at a national level. State and local agencies are likely to be more familiar with highways in their jurisdiction and significant activities or events that have affected system performance. Some State and local agencies may be monitoring performance using other methods or techniques that could confirm or differ from national congestion monitoring results. Because of their experience with local issues, State and local agency staff may also serve as a "reality check" for data collected in national congestion monitoring. However, this capture of local knowledge is currently, at best, an informal process that involves sporadic communication with State and local agencies. There appears to be a need to formalize a process (perhaps in the form of a Delphi group) that solicits the knowledge and experience (as well as "event" databases) of State and local agencies in national congestion monitoring.

TTI researchers have been gathering this local knowledge for many years through several of their national congestion studies. In the media-friendly Urban Mobility Study, which currently reports congestion statistics for 75 cities using Highway Performance Monitoring System (HPMS) data, TTI researchers regularly contact State DOTs and metropolitan planning organizations to better understand or interpret reported trends in road mileage and travel statistics. This contact has been essential for smoothing year-to-year fluctuations caused by reporting differences or inconsistencies. Similarly, in the Mobility Monitoring Program, which reports congestion statistics for numerous cities using archived data, TTI researchers informally solicit feedback on city-specific reports that contains route-by-route congestion and reliability statistics. In most cases, State or local agencies have confirmed the overall trends reported. However, some State or local agencies occasionally dispute the credibility of the archived traffic data as compared to their local congestion studies or experience. Many times these agencies are not currently using archived data for local performance monitoring. If they were, local knowledge could help improve both data quality and use of the data for national purposes. Therefore, a lesson learned is that local use of archived data for performance monitoring will benefit national efforts and should be promoted.

4. NEXT STEPS

4.1 Improve Traffic Detector Data Quality at Its Source

A high level of data quality is absolutely essential for an archive to be useful to a wide variety of interests (including performance measurement. If users perceive that the data are not of sufficient quality, the archive will not get used and interest will wane. The best way to ensure quality data is to have the original collectors (owners) take responsibility for it. This includes developing formal review procedures (which can be automated through software), routinely publishing data quality statistics, and establishing a feedback process whereby users can alert collectors/owners of quality problems not originally detected. However, that is the easy part. A much more difficult part of maintaining a high level of data quality is ensuring that field devices are properly installed, calibrated, and maintained. These activities require significant investment by data collectors/owners.

> **Actions:** It would be useful to document the costs of proper detector installation, calibration, and maintenance activities, especially with regard to type of equipment and the level of data quality (accuracy in the field measurements) achieved. Identifying best practices for each of these activities would also foster archive development and use. Promoting the use of quality control software by data collectors/owners (i.e., TMCs) would also support maintenance of quality data.

4.2 Presentation and Use of Congestion Performance Measures by Transportation Agencies in Decision-Making

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

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

4.3 Integrate Event Data at the Local Archive Level

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

> **Actions:** (1) An effort should be undertaken to harmonize the data requirements required for documenting roadway events from performance measurement and archive perspectives as opposed to purely an operational perspective. This involves review of and potential modification to existing ITS standards (especially the TMDD and 1512 "family") and standards used in the data systems of nontransportation agencies (especially police computer-aided dispatch systems. (2) A scan of current event/traffic data integration practices among ITS data archives would reveal best practices and potential pitfalls.

4.4 Document Comparative Analysis of Congestion Monitoring Methods

As shown previously in Figure 2.1, several methods are available for developing congestion performance measures. Many areas must use a mix of these measures depending on the availability of data from deployed ITS. For example, some roadways may have detectors, others may have problem systems, others may have travel times collected by floating cars, and others may only have purely modeled travel times. However, the relationship of all these methods to the measures they produce has not been determined. For example, how compatible are estimates from detectors versus those from probes versus different models – are they reasonably close or wildly different? Are there ways to adjust one method to match another?

> **Actions:** A study utilizing data from a variety of sources within 1-2 metropolitan areas should be explored. Original data collection to establish a baseline ("ground truth") may be required. Data should include roadway detectors, vehicle probes, and transportation models at a minimum.

4.5 Performance Measurement Self-Assessment

Self-assessments have been used successfully in the emerging fields of operations. Self-assessments are essentially expanded checklists that agencies can use to compare their current activities to an accepted practice. They are very useful in allowing agencies to identify areas that they have not considered; once identified, they can seek out additional guidance.

> **Actions:** It is recommended that an operations performance measurement self-assessment process be developed for use by State and local transportation agencies. The self-assessment can be based on much of the work presented in this report and should include several features:

- Identification of good, better, best practices in monitoring the performance of transportation systems from an operations perspective. Monitoring should include:
    - System performance from the user's perspective ("outcome" congestion/mobility metrics based on travel time)
    - System performance from the agency's perspective ("output" metrics such as the incident timeline; work zone activities and durations)
    - Safety
    - Emergency preparedness
- Institutional relationships required for data collection and for improving field activities
- Measurement methods/models and data collection programs

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