Collecting, Processing, Archiving and Disseminating Traffic Data to Measure and Improve Traffic Performance

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ABSTRACT

Current practices in using archived operations data collected by traffic management centers (TMCs) to measure performance were surveyed and analyzed. There are three major findings. First, better utilization of archived data will take time and experimentation with data. Typically, the regions in which data archiving and performance monitoring are most prevalent and widespread are those in which local/state agencies have been archiving and analyzing data for at least 5 or 10 years.

Second, archived traffic data should be used to improve traffic management center performance. Many TMCs view their mission solely as "crisis management," seeing little connection between historical archived data and the crises they manage on a day-to-day basis. However, many "operations-based" organizations make extensive use of "archived" operations data because their profits depend upon their ability to exploit that data to develop ways to operate more efficiently and effectively.

Finally, the key to effective use of archived data is clear assignment of responsibility and adequate funding. Although archived data are useful to operators, planners, researchers, air quality analysts, transit providers, consultants, media, and others, in most cases the data are being maintained by TMC personnel whose equipment collects the data, but who may have neither the resources nor motivation to make the data easily accessible.

INTRODUCTION

Purpose of the Study

Under the rubric of intelligent transportation systems (ITS), many transportation agencies have established transportation management centers, which collect traffic data for use in traffic operations. Although intended primarily for use in real time, these data can be archived and used in many other ways to measure performance and inform decisions of transportation system providers and users. But establishing and maintaining a system to collect, archive, and disseminate traffic data is a challenging undertaking. In order to provide guidance to agencies wishing to establish such a system, the departments of transportation in Texas, Minnesota, Washington, and California and associated research organizations conducted a pooled fund study of the elements of such systems and current practice in using archived traffic data for measuring performance.

Traffic Performance Measure System Structure

Traffic performance measures have several potential uses. They can be used to measure the state of the system, the traffic volumes, the distribution of travel time and delay, vehicle emissions, and the safety of the facilities. This tells decision-makers where improvements are needed and where needs are greatest and thus can inform decisions regarding where to allocate resources and the total level of resources to seek.

Evaluating actual changes in operating strategies or capital improvements by comparing performance before and after provides a basis for estimating the effects of future actions. If "before and after " performance is available, the performance of two different facilities can be compared and inferences made regarding the effects on performance of differences in operations, facilities or demand.

Even the traffic information used to inform travelers and manage traffic in real time can be thought of as performance measures. So performance measures can inform the decisions of travelers as well as system operators and people who plan operations, design facilities, develop capital programs, and allocate funds.

The process of creation and use of performance measures can be thought of a circle in which measures of traffic conditions are used to inform actions by the users and providers of transportation, which in turn, affect the traffic conditions. Figure 1 shows the components of a traffic performance measure system.

The traffic conditions are recorded by some type of sensor, which transforms what is sensed into a standard format that is recognized by the data processor. Some type of communication system sends the data to the processing location. The raw data from the sensors is processed into performance measures, ideally into multiple formats for multiple users. The performance measures are disseminated to users immediately or may be archived for later dissemination or retrieval. Users of the performance measures make decisions that, in turn, affect traffic. This is the ideal. In most regions the circle is broken at some point for most, if not all, users. For a particular type of decision-maker the circle can break down at many points:

- there may not be functioning sensors at critical locations
- the communications may not be in place or may not be functioning properly
- the data processing may not include sufficient checks for errors and may not provide information in a useful form for all users
- data may not be archived for a long enough period
- dissemination methods may be inadequate
- decision makers may not have good tools or sufficient resources to fully utilize the performance measures for decision making.

This paper generally follows the circle shown in Figure 1, first discussing the decisions and the performance measures needed to inform each type of decision. Then various types of sensors, communications, and data processing tasks are discussed. In each section, the state of the practice is described. The report concludes with recommendations for improving the traffic performance measure system.

DECISIONS INFORMED BY TRAFFIC PERFORMANCE MEASURES

Table 1 shows the different groups of potential data users. Although they use similar data, the format of the data will be quite different.

In many of the areas surveyed, performance measures were much more prevalent at the MPO or planning level than at the operations level. At the planning level, performance measures are used for investment analyses and project prioritization. Only a few of the operating agencies surveyed are using or are planning to use performance measures. Washington DOT produces an annual report of performance measures using archived operations data on major freeways. Caltrans is developing a system that collects and archives loop data, creates various performance measures and make them available on the Internet.

Travelers and Commercial Vehicle Operators

Travelers make decisions regarding departure time, route, mode, and destination as well as whether to travel or not. Although these decisions are based primarily on the activities the trip serves, the value of these activities, and the locations at which these activities can take place, they are also based on traffic conditions, such as travel time, the variability of travel time, ease of driving, and safety. Similarly, commercial vehicle operators' decisions are based primarily on cargo origins and destinations and other customer needs, but their decisions regarding routes and times of day to travel are based on traffic conditions. Both groups are most interested in the locations of incidents and travel times.

Transportation System Operators

The primary tasks of operators are incident management, ramp metering, lane control, and the provision of traffic information. The decisions they make are how to manage incidents, what metering rates to use, what hours to operate HOV lanes, and what information to provide to travelers and traffic information providers, such as radio stations.

Although incident detection relies heavily on 911 calls, and incident response decisions depend on personnel at the incident site or CCTV when it is available at the incident site, most other decisions made by operators depend on speeds, volumes, and travel times. These include decisions regarding where to position warning-sign trucks in case of an incident and what ramp metering rates to use at various locations at various times of day, as well as what traveler information to provide.

Historical (other than real time) speed, volume, and travel time data is used for scheduling maintenance and construction activities. These data are also used to plan operational strategies, such as what hours to operate HOV lanes and what time-of-day ramp metering rates to use. Historical incident information is used to develop strategies to deal with future incidents. It and the historical traffic data may be used to justify additional investment in resources to manage incidents or recurring congestion or to gather information.

Operators need detailed site- and time-specific information. In California, loop detector data are typically reported at 30-second intervals. This level of detail is useful for locating an incident or the location of the end of a queue. It can be averaged over longer time periods for other uses, such as traveler information or scheduling maintenance and construction.

Capital Investment Planners and Facilities Designers

Historical speeds, volumes, and travel times tell decision-makers at many levels where delay is worst. They can be used to allocate funds between regions and between projects within a region, as well as for the design of projects. In order to locate and design facilities in a way that is most cost-effective in reducing delay, planners must have volume and speed data for other facilities that might be affected by changes in capacity in these locations. Facility designers need information on ramp and mainline volumes in order to provide extra capacity where needed and not where it would not reduce delay.

Data Characteristics

Although many types of people use the same measures, the data characteristics they need for a particular measure may be different:

- geographic scope – a facility designer needs data only for the area that will be affected by the facility, whereas a system operator needs data for the entire congested region
- geographic aggregation – a planner needs accident data by specific location in order to determine where safety improvements are most needed, whereas a policy maker needs overall accident data in order to decide what level of resources to assign to safety improvements

- temporal scope – a traveler unfamiliar with the area may want travel time for any time of day, whereas a system operator may need it only for congested periods
- temporal aggregation -- system operators typically use volumes aggregated over intervals of less than a minute, but facility designers can use more aggregated data
- currency – real-time data are needed for applying operational strategies, but historical data are needed for developing these strategies
- accuracy – traffic adaptive ramp metering requires very accurate measures, but travelers can accept a higher level of error—a travel time estimation error of 2 or 3 minutes would be considered acceptable by most travelers
- availability – traffic adaptive ramp metering requires that data be available when the meters are operating, but less consistent availability is required for planning, which utilizes data over a longer period of time, requiring only that data be available for locations of interest at least some of the time

These differences imply a need for archiving data in a large database that can be easily accessed by the various users and for providing software with which various users can select, aggregate, and format the data most appropriately for their uses.

Traffic Performance Measures Derived from Data Collected by TMCs

These are the performance measures that can be derived from the type of data collected by TMCs:

- travel time – can be measured directly or estimated from spot speed or volume and occupancy measurements
- speed – spot speeds can be measured at detector locations using double loops or estimated vehicle lengths or they can be inferred from travel times
- reliability – this is the variance in travel time, which can be estimated from the distribution of travel times
- safety – can be measured by the rate and absolute number of various types of accidents by specific location, link, or area, by time of day, week, or year or by weather conditions.

Traffic volume, a key measure for making decisions regarding how to reduce travel time, as well as density, which, with volume determines travel time, are generally not included in agencies' lists of performance measures. However, they are included as such in this paper because of their widespread usefulness. Furthermore, volume is a measure of the use of the transportation system, and therefore of its benefit.

How Are TMC-Collected Performance Measures Currently Being Used?

Most TMCs use their real-time data to manage incidents and provide roadside information. Many make incident data and speed data available to travelers, either directly via the Internet or through a traveler information provider. The most common uses of archived data by operations staff appear to be:

- Intelligent transportation system (ITS) evaluations – archived data are used to compare conditions before-and-after deployment of new operational strategies;
- Work zone management – data are used to determine optimum times or penalty costs for freeway reconstruction and maintenance activities; and
- Performance monitoring – a few agencies use the data to monitor performance on a monthly or annual basis.

The most common uses of archived data by other agencies appear to be:

- Research on ITS and operations – research agencies use archived data to develop and/or evaluate operating strategies (e.g., ramp metering) and algorithms (e.g., incident detection).
- Planning analyses – planning agencies use archived data for numerous activities, such as model calibration, traffic volume factors and characteristics, and congestion management programs.
- Air quality analyses – air quality analysts are beginning to use archived data to develop and calibrate mobile source emissions models.

Few TMCs have routine methods of data access for other users, although some provide data to universities, planners, or consultants upon request. An exception is the Seattle TMC which, as part of the TRAC project, has been archiving detector data and making it available to other users for several years. It currently produces a CD of traffic data every 3 months. California is implementing a Freeway Performance Measurement (PeMS), an on-line database of loop detector data that can be downloaded in a variety of formats. Other TMCs are developing systems whereby another agency, such as a research institute or metropolitan planning agency archives the TMC data for access by other users.

SENSORS

Linking Measures to Types of Sensors

Table 2 shows the types of data provided by various types of sensors. Two X's indicate that the source provides good information and one X indicates that the source provides some information.

Travel times can be estimated from point speeds at road based sensors, but they can be more accurately estimated by vehicle probes or platoon or vehicle tracking using various features captured by road based sensors and/or video cameras. The latter are currently under development, and may shortly elevate road-based sensors to XX status for collecting travel times. However, with vehicle-based sensors, travel times can be measured directly. Road based sensors are the best means for measuring flows and densities. Reliability is calculated from the distribution of travel times.

Sensor Types and Performance

Primary considerations in selecting detectors are: accuracy of information, reliability, purchase and installation costs, operations and maintenance costs, and useful life span. Less than optimum maintenance may reduce maintenance costs but it will likely also reduce accuracy, reliability and life span. The detectors currently available are described below.

Road-based Sensors

Loop Detectors These are the most commonly used detectors. They sense when a car enters the pavement over the loop and how long it covers the loop, thus providing a count of vehicles crossing the loop and a measure of the time the loop is occupied, from which the vehicle density (vehicles per mile) can be estimated. Loop detectors are sometimes installed in pairs with one a few meters upstream from the other, so that speed can be more accurately estimated. Loop detectors are not always accurate and often are non-functional. The inductance can change with temperature, rain, corrosion, and mechanical deformation. The controller can malfunction, data can be processed in a way that causes errors at low traffic levels, and communications can malfunction or be interrupted. Performance can be enhanced by correcting any shortcomings in the infrastructure surrounding the detectors, updating the controllers used for the loop detectors, updating the communications system for sending loop data to the TMC, and installing "health check software" to identify non-performing and potentially inaccurate loops. Inductive signature detector cards that can automatically adjust for changes in the loop characteristics that cause errors have been developed. These cards can also be used to identify trucks and for matching inductance patterns of vehicles at successive detectors in order to obtain travel times between the detectors [Ritchie and Sun, 1998]. Double loops can be used to measure the lengths of vehicles or groups of vehicles so that they can be matched at successive detector sites. This method is currently being used to estimate travel times on I-80 near Berkeley, California. [http://www.its.berkeley.edu/projects/freewaydata]

New loop geometries that provide higher spatial resolution and fewer pavement cuts are being developed. Already developed are micro loops, which are placed in tubes installed a few feet below the roadway. They are less sensitive and have lower resolution than conventional loops but they are less vulnerable to damage and can often be installed and replaced from the side of the road.

RADAR Detectors Like loop detectors, these detectors provide counts and density. They are commercially available and have been installed in locations in the United States, Asia, and Europe. However, they are not yet widely deployed for freeway traffic monitoring. They are mounted on the side of the road and are relatively easy to install. One sensor can monitor several lanes of traffic. One supplier has agreed to bundle each detector with a solar electric panel and wireless communication so that they can be installed in locations without electricity or telephone connections.

Video Image Detection Systems These have been commercially produced for several years and have been used for actuated intersection detection, automated traffic counts, ramp metering, freeway management and automatic incident detection. Like loop detectors, they can count vehicles and determine presence. Some can also read license plates so that vehicles can be reidentified in order to estimate travel times and origin destination patterns. However, their accuracy can be compromised by occlusion of vehicles, glare, day-night transitions, and reflections from wet roads.

Comparison of Road Based Sensors Tables 3 and 4 show the results of a Texas Transportation Institute study of road-based detector performance. [Middleton, Jasek, and Parker, 1999]. These tables are based on data from 1997 and 1998 and so do not reflect the latest performance levels. Also, performance can be influenced by local conditions and particular configurations. The costs displayed in these tables include costs of poles and mast arms. The data for loop detectors does not include traffic control and motorist delay costs during installation, which would both be greater than for the competing non-intrusive detector technologies.

Closed Circuit Television

Video cameras, especially those with remote pan, tilt, and zoom, are widely deployed for traffic monitoring. Video feeds to television and the Internet are favorites with travelers because they give an immediate, comprehensive picture of traffic conditions. They are also useful for planning and managing incident response if the incident is in a camera's field of view. Providing communications between the cameras and the TMC can be expensive. However, systems to provide solar power at the camera site and wireless communications can reduce these costs and the cost of installation.

Vehicle Probes

This is the simplest and most accurate way to obtain travel times (actually distributions of travel times) between two points.

Toll Tag-equipped Vehicles The probe vehicle method that has been most widely deployed uses transponders (generally already used for electronic toll payment) that are read at various locations. When the same vehicle is read at two locations, the travel time between the locations can be calculated. If enough vehicles are equipped with transponders and there are enough readers, this can also provide origin/destination patterns. Incidents can be detected quickly by a sudden and unexpected drop in travel times. Houston is the city where this type of system has been used most extensively. It has also been used in San Antonio and on a limited basis in New York and New Jersey (the Transmit program), where there are plans to extend the system.

Vehicles with Cell Phones The tracking of cell phones promises to provide large amounts of low-cost travel time information, but this technology is still in the early development stage. A test is currently underway in Maryland.

GPS-equipped Vehicles GPS systems and wireless modems can be installed in vehicles and can be programmed to send a signal to the TMC whenever it passes locations of interest, such as major streets. This system, is also still under development.

What Types of Detectors Are Currently Being Used?

Most agencies use some loops, many use double loops. Spacing is often ½ mile, but ranges up to 2 miles. The area covered in Detroit is 180 miles, but coverage is much less in most areas. A few agencies use radar, microwave, acoustic, or video image detection. Only Houston, San Antonio and New York/New Jersey use vehicles equipped with toll tags as probes. In Houston the readers are spaced every 2.8 miles on average. All agencies use CCTV.

COMMUNICATIONS

Communications are a crucial component of the traffic performance measure system and have a large impact on both costs and performance of the system throughout its lifetime. The best communications technologies to use for communicating traffic data will depend on the nature and volume of data, distances between where the data is collected and processed, communication services available in the area, and their cost.

Technologies

There are two categories of communications technologies: wireline and wireless. Wireline technologies include:

- Twisted pair copper
- Coaxial cable
- Fiber optic (multimode and single mode).

Wireless technologies include:

- Microwave
- Cellular (digital and analog)
- Cellular digital packet data (CDPD)
- Spread spectrum
- Digital and trunked radio systems.

Fiber optic communications are the fastest and most reliable, but installation costs are high. Wireless communications have much lower installation costs but are slower. Cellular communications are readily available in many areas but are considerably slower than other media.

Network Topology

There are also choices in the way in which the communication links are connected. These are shown in Figure 2.

What Types of Communications Do Agencies Currently Use?

Fiber optic cable is a preferred communication medium because of its high capacity and reliability, but it is too expensive for many locations. However, some departments of transportation have been able to obtain low cost fiber optic service as part of the compensation for allowing communications companies to lay fiber optic cable in their rights-of-way. Leased telephone lines have been a common medium, but agencies must make sure that the carrier is providing reliable service. Increasingly, agencies are shifting to radio modems, which are generally less expensive than leased telephone lines. Most agencies use a combination of communications media. For example, Detroit has a fiber optic ring with microwave spokes to hub locations from which copper cables are linked to the field devices. Virginia DOT uses coaxial cable inside the beltway around Washington DC and fiber optic outside the beltway.

DATA PROCESSING

Some processing takes place at the sensor site, where the raw data is generally converted into traffic data. For example, with a loop detector the magnetic impulse is generally processed into an average flow and occupancy for a short time interval, such as 30 seconds. Or the data may be averaged over only 1 second, or the times between successive impulses may be calculated. The ultimate uses of the data will determine how the data should be processed at the detector site before transmission to the traffic management center. However, the more detailed the data that is transmitted to the traffic management center, the higher the communications cost. Therefore, an agency may choose to transmit data at the level of detail needed for real-time traffic operations and to accumulate samples of more detailed data at the sensor site, to be retrieved manually or transmitted to the center off peak.

Data Quality

Quality has a number of aspects:

- Accuracy -- a high level of accuracy is needed for optimal ramp meter control, but a much lower level of accuracy will suffice for travel time estimates for travelers.
- Reliability -- the data collection system should be maintainable with available resources at the level of reliability needed for it to be useful. Experience with all types of detectors indicates that reliability requires a significant level of maintenance.
- Absence of Bias – this refers to the extent to which the sensor data reflects the entire facility or network being monitored. Because point detectors sense traffic at only one point, to be truly representative they should be located wherever the traffic conditions would differ from adjacent locations, for example on an on-ramp and between each pair of ramps. In a probe vehicle system utilizing toll tags, spacing of toll tag readers determines

the level of geographic aggregation, and the number of probe vehicles needed to adequately represent conditions between each pair of readers depends on the variance in vehicle speed and the rate at which speed is changing.

- Validity of estimation methods – in some systems, missing data is replaced by estimated data; users who are unaware of this practice can draw erroneous conclusions from the data. Data collection, processing, and error handling methods should be documented and readily available to all data users.

How Do Agencies Currently Control Quality?

Most agencies use some type of basic error checking that identifies physically impossible or implausible data values, such as average 5-minute speeds greater than 80 mph or total 5-minute lane vehicle counts greater than 250. This error checking is performed at either the detector controller level or the central database/archiving level. Most agencies will set data errors to special codes (e.g., "-1" or "255"), but few provide information or codes as to why the data was considered erroneous and dropped.

A few agencies use more sophisticated error checking, such as checking for implausible *combinations* of data values, such as occupancy less than 5 percent but speed less than 20 mph. Researchers at several locations have developed more sophisticated error checking procedures, but these have not been implemented because a) they require more data than is typically available in real-time or through the controller or b) the error checking algorithms are too complex for most operating agencies to implement.

Some agencies prepare reports on which devices are not reporting. Some do maintenance on a weekly cycle, some on a daily basis. Generally those agencies that find loop detectors to perform well are those that investigate any lack of signal or apparent error as soon as it occurs and then make prompt repairs.

Data Archiving

The huge reductions in the cost and space required for storing data have made it possible to archive orders of magnitude more data at a higher level of detail than would have been possible even a few years ago. However, managing and retrieving data still requires significant resources unless the storage and retrieval process can be highly automated.

Although the archived traffic is useful to planners, facility designers, and researchers, meeting their data needs is generally not considered a responsibility of the people at the TMC who collect the data, whose mission is to manage traffic, particularly incidents. This presents an organizational problem that must be overcome if full use is to be made of the traffic data. One way is to transfer the TMC data to another agency or organizational units whose responsibility is to archive the information and make it available to all potential users in a useful format.

How Is Traffic Data Currently Archived, Managed and Disseminated?

A USDOT study found that over 80% of agencies collecting traffic volume data archive that data and over 60% collecting speed data archive that data (see Table 5). In many locations, the de facto group for maintaining a data archive has been the operations workgroup/agency, since they are simply saving their own data. However, in some of these locations, the operations workgroup only maintains "recent" data until it can be transferred to some other group/agency for ultimate long-term storage and/or management. In some cases, the operations workgroup archives data in a convenient storage format (compressed text) but does not make the data accessible or easy to use or analyze.

In a few areas, the MPO or another agency has taken the lead in maintaining and managing a data archive for themselves and other agencies in the region. These data archive managers then consider themselves responsible for providing these basic data archive functions:

- Performing quality control
- Ensuring that the data is easily accessible, either through the Internet or on CDs by request.
- Providing information and documentation on the data.
- Providing software applications that help to analyze the data, or providing data formats that can be easily analyzed by other's software.

For example, the operations group in Washington DOT has developed analysis software and publishes an archived data CD every 3 months. In California, Caltrans has taken the lead in developing a performance measurement system (PeMS) that makes archived data and various data summaries available through a web site. In Virginia, the Virginia Transportation Research Council has been charged with maintaining statewide ITS data archives, and handle the long-term management and distribution of this data. With a few exceptions, agencies that are using archived operations data for significant analyses are storing that data in a relational database (e.g., Oracle, Sybase, Informix, SAS). Access to the data in a relational database is then provided by using either special programming languages (e.g., SQL, or structured query language) or through a graphical user interface, such as a web browser or database query window. In most cases, the use of a relational database also requires a database administrator who manages day-to-day operations of the database and develops user applications.

The storage period for data archives varies depending upon data uses, but most agencies use some type of data cataloging process whereby the most recent data is kept "on-line" (e.g., a computer hard disk drive) and older data is kept "near-line" or "off-line" (e.g., CD or magnetic tape cartridges). Nearly all agencies do keep a permanent archive, with very few "erasing" or disposing of old data. Several agencies are planning to have the most recent 12 months on-line and available, whereas owners of smaller archives maintain several years on-line. Additionally, some agencies keep summaries (such as hourly averages) of older data on-line while permanently archiving detailed data (such as 1 or 5-minute data).

CONCLUSIONS AND RECOMMENDATIONS

Better Utilization of Archived Data Will Take Time and Experimentation

Archived data are a rich resource for improving all types of transportation decisions, but are rarely fully utilized. Typically, the regions in which data archiving and performance monitoring are most prevalent and widespread are those in which local/state agencies have been archiving and analyzing data for at least 5 or 10 years. For example, the archived data in Seattle has been widely distributed for at least the past 5 years and has become institutionalized. This finding suggests that agencies in other regions may be likely to adopt archived data for performance monitoring once they 1) learn more about how much and what data is available from this traffic sensors; 2) have the quality and use of that data demonstrated through practical applications; and 3) experiment with archived data to ensure that it meets their needs. Changing the way that institutions make decisions, particularly costly infrastructure investment decisions, is slow and evolutionary. However, it is hoped that this paper may help TMCs build upon the experience of other TMCs, thus reducing the time needed to fully implement a performance measurement system based on archived traffic data.

Archived Traffic Data Should be Used to Improve Traffic Management Center Performance

This survey of TMCs found that many view their mission solely as "crisis management." Some see little connection between historical archived data and the crises they manage on a day-to-day basis. However, numerous other "operations-based" companies inside and outside of transportation make extensive use of "archived" operations data because their profits depend upon their ability to exploit that data to develop ways to operate more efficiently and effectively. For example, trucking and package delivery companies keep extensive records of package locations and times, and then analyze these shipping times to find locations of inefficiency. Most automated manufacturing facilities track performance of certain machines or equipment to ensure maximum efficiency. Similarly, TMCs should analyze performance data to determine the optimum way to manage crises and to develop other means of operating the transportation system at its maximum efficiency. Because most TMCs are already short of resources, more resources will be needed to accomplish this mission.

The Key to Effective Data Archiving Is Assignment of Responsibility and Adequate Funding

There are numerous users of archived data: operators, planners, researchers, air quality analysts, transit providers, consultants, the media, and others. Although we found several institutional models used in maintaining ITS data archives, in most cases the data are being maintained by operations personnel simply because they own the equipment that collected the data. This can be burdonsome for a TMC, particularly if the operations agency does not use the data. What is needed is a "transportation information services" unit that can collect and disseminate this type of data. In some areas, metropolitan planning organizations are preparing to fill this role (e.g., Dallas-Ft.

Worth, Cincinnati, Detroit). In other areas, the state or local DOT has taken on this responsibility (e.g., California, Seattle, Houston, Atlanta, Phoenix). The determination of which agency maintains data archives has strongly depended on existing institutional structures and relationships. Although there are many possible models, and it is not clear whether one model is better than the others, it is clear that an adequately funded organizational unit responsible for archiving and disseminating the data is essential to obtaining the full benefit from the traffic data that TMCs collect.

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LIST OF TABLES

LIST OF FIGURES

TABLE 1 Traffic Performance Measure Needs of Various Potential Users

Data Item	Travelers and Commercial Vehicle Operators	Traffic Information Providers	Transportation System Operators	Planners and Policy Makers	Facility Designers	Researchers
LINK-BASED INFORMATION						
Real-time link travel times	X	X	X			
Historical link travel time distributions	X	X	X	X	X	X
Current link densities and flows and historical distributions of link densities and flows		X	X	X	X	X
Raw Traffic Data						X
INCIDENT INFORMATION						
Real-time indication of incidents	X	X	X			
Real-time incident particulars	X	X	X			
Historical incident records		X	X	X	X	X

TABLE 2 Data Sources for Various Data Needs

Data Item	Road-based sensors other then Closed Circuit Television (CCTV)	CCTV	Vehicle-based sensors	Patrol/Traveler Call-in
Link travel times	X	X	XX	
Link densities and flows	XX	X		
Incident detection	X	X	X	XX
Incident details		XX		X

TABLE 3 Quantitative Evaluation of Detectors at Signalized Intersections[a]

Technology/Product	Intersection Cost	Detection Accuracy (%)	
		Overhead	Sidefire
Inductive Loops	$3,278	98	NA
Active Infrared	14,520[b]	97[c]	NA
Passive Infrared	8,051	97	NA
Radar	3,590	95	90
Doppler Microwave	6,496	NA	NA
Pulse Ultrasonic	6,350	NA	NA
VIDS	3,370	95	82

[a]Four-by-four intersection with single left-turn lane.
[b]Assumes four poles with mast arm are needed; no motorist delay or traffic control included.
[c]Dropped to 77 percent in inclement weather.

Source: Texas Transportation Institute

TABLE 4 Quantitative Evaluation of Detectors on Freeways[a]

Technology/Product	Cost/Lane[b]	Overhead Accuracy (% of ILD)		Sidefire Accuracy	
		Count	Speed	Count	Speed
Inductive Loops	$746	98	96	NA	NA
Active Infrared	1,293	97[c]	90	NA	NA
Passive Infrared	443	97	NA	97	NA
Radar	314	99	98	94	92
Doppler Microwave	659	92	98	NA	NA
Passive Acoustic	486	90	55	NA	NA
Pulse Ultrasonic	644	98	NA	98	NA
VIDS	751	95	87	90	82

[a]Six-lane freeway.
[b]Includes cost of pole with mast arm for active IR; includes no motorist delay, but does include traffic control costs for ILDs.
[c]Dropped to 77 percent accurate in inclement weather.

Source: Texas Transportation Institute

TABLE 5 Summary of Data Archiving Practices as Reported to U.S. DOT, 1999

Type of System	Type of data	% of agencies archiving
Freeway Management	Vehicle traffic volumes	87% (59 of 68)
	Vehicle classification	76% (37 of 49)
	Traffic incidents (time sequence of events, location, cause, number of lanes blocked, etc)	67% (35 of 52)
	Vehicle speeds	66% (31 of 47)
	Current and scheduled work zones (location, number of lanes closed, scheduled duration, etc)	53% (34 of 64)
Arterial Street Management	Vehicle traffic volumes	83% (134 of 162)
	Turning movements	83% (94 of 113)
	Traffic incidents	83% (34 of 41)
	Phasing and cycle lengths	80% (91 of 114)
	Vehicle speeds	79% (80 of 101)
	Traffic signal preemption info	75% (46 of 61)
	Current work zones	72% (52 of 72)
	Scheduled work zones	67% (43 of 64)

Source: U.S. DOT ITS Deployment Tracking Database, 1999 Results.

FIGURE 1 Components of a Traffic Performance Measures System

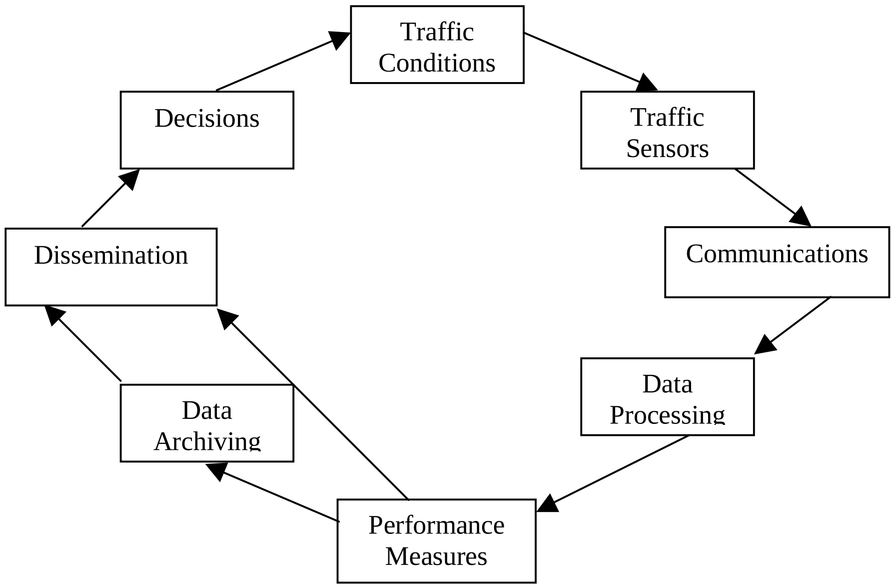
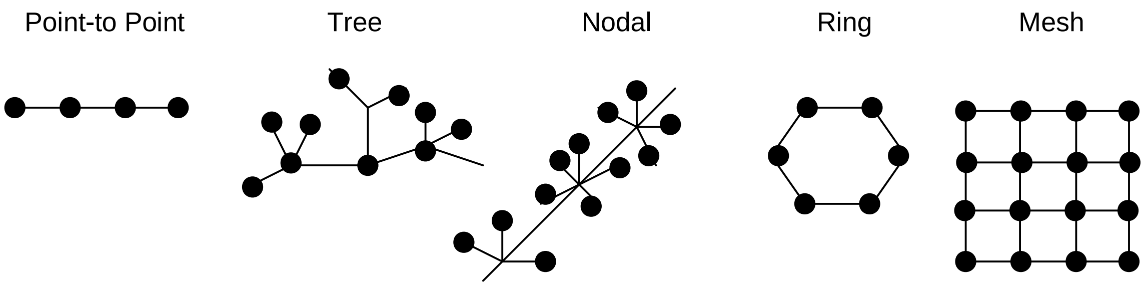


FIGURE 2 Possible Network Topologies



Source: Federal Highway Administration, Joint Program Office, *Communications for Intelligent Transportation Systems, Successful Practices, Reaching Cost-Effective Solutions through Better Decision-Making Techniques, August 2000*