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CALIFORNIA PATH PROGRAM  
INSTITUTE OF TRANSPORTATION STUDIES  
UNIVERSITY OF CALIFORNIA, BERKELEY

# **Traffic Management Systems Performance Measurement: Final Report**

**James H. Banks, Gregory Kelly**  
*San Diego State University*

**California PATH Research Report  
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# **TRAFFIC MANAGEMENT SYSTEMS PERFORMANCE MEASUREMENT**

## **FINAL REPORT**

by

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## **ABSTRACT**

This report documents a study of performance measurement for California Department of Transportation (Caltrans) Transportation Management Centers (TMCs). Performance measurement requirements were analyzed, data collection and management techniques were investigated, and case study traffic data system improvement plans were prepared for Caltrans districts in San Diego and Orange County. Performance measurement is appropriate for 1) the evaluation of operational changes and investments in TMC functionality and 2) traffic system monitoring. It is normally not appropriate for comparisons between different TMCs or evaluation of the long-run impact of TMCs. Major TMC functions include ramp metering, incident management; traveler information; motorist assistance; and data collection, management, and dissemination. Important measures of effectiveness related to these include travel time and related measures, ramp delay, traffic volumes and vehicle-miles of travel, accident rates, traffic information accuracy, incident clearance times, and equipment status. Traffic data systems in the two districts studied in detail are generally adequate to support performance measurement, but there is a lack of staffing and institutional infrastructure to support evaluation studies, performance monitoring, and data quality control. Possible actions to improve performance measurement include development of a policy for evaluation of investments in TMC functionality, research to compare loop-detector-based travel time estimates with measured travel times, development of a quality control system for traffic information, development of a traffic system performance monitoring system plan, research concerning the feasibility of relating incident and accident data, further research on non-loop-based travel time measures, extension of loop detector coverage, and development of data reduction and display software for performance monitoring.

**Key words: Performance measurement, traffic systems management, transportation management centers, traffic data collection**

## EXECUTIVE SUMMARY

This report documents a study of performance measurement for California Department of Transportation (Caltrans) Transportation Management Centers (TMCs). Project objectives were to 1) analyze performance measurement requirements associated with Caltrans TMCs, 2) identify and assess the feasibility of data collection and management activities required to support TMC performance measurement, 3) recommend specific actions by Caltrans and PATH that will facilitate performance measurement, and 4) propose specific Traffic Data System Improvement Plans for two Caltrans districts..

Performance measurement is *the evaluation of a traffic system or some component thereof based on quantitative measures of system output, quality of service, environmental impact, or similar features*. Performance measurement objectives include evaluation of investments in TMCs or TMC functions, rationalization of operating budget allocations, monitoring to identify traffic system and traffic management system changes that require a response, reporting to inform elected officials and the public about system status and agency performance, and research to advance understanding of traffic phenomena and the traffic management system. The objects of performance measurement include the overall highway traffic system, TMCs or other units involved in traffic system management, and specific TMC functions. Important TMC functions include ramp metering; incident management; traveler information; motorist assistance; and data collection, management, and dissemination.

Performance measurement usually involves measuring some feature of the performance of the traffic system (such as travel time) and using this to infer the performance of some part of the traffic management system (such as a TMC function). Performance measurement study designs provide the logical link between traffic system performance and traffic management system performance. A major issue in the design of performance measurement studies is how to separate the effects of the performance of the object of the study from the effects of external circumstances, such as demand patterns, network configurations, or physical designs. Common study designs include *longitudinal*, in which data for a given location (say a freeway section) are compared over time, and *cross-sectional*, in which data taken simultaneously at several locations are compared. In most cases, longitudinal study designs are appropriate for performance measurement studies, since it is reasonable to suppose that external circumstances do not change significantly over the periods of time involved in the study. On the other hand, it is rarely reasonable to assume that external circumstances do not vary significantly by location.

Longitudinal studies are appropriate for most combinations of performance measurement objective and object. Exceptions are budget allocation decisions among TMCs, where the problem is inherently cross-sectional, and situations in which so much time has elapsed that the assumption of no significant change in external circumstances is no longer valid. For instance, it is not really possible to determine the benefit of a TMC that has been existence for many years, even if “before” data are available, because it is impossible to say what traffic conditions would be without the TMC. Based on an analysis of the

interrelationships among performance measurement objectives, objects, and study designs, it appears that two basic types of performance measurement are feasible: 1) before-and-after evaluation studies of investments and operational changes and 2) routine monitoring of traffic data to identify changes in the traffic system that require a response.

Major measures of effectiveness related to TMCs and TMC functions include travel time and related measures such as speed, ramp delay, traffic volumes and vehicle-miles of travel, accident rates, traveler information accuracy, incident clearance times, and equipment status.

There are a variety of issues related to the measurement of these performance indicators. Travel times, for instance, can be estimated from loop detector data. This method takes advantage of an automatic data collection system that is already well-developed in many parts of California, but there are questions about the accuracy of the data; also, the existing system does not cover all geographical areas equally well. Other techniques for measuring travel times, such as use of probe vehicles, are under development but still not ready for widespread implementation.

At present, measurement of ramp delays requires hand counts and is consequently very expensive. Traffic volumes are readily available through the traffic census program and from loop detector systems associated with surveillance and ramp metering systems. Accident data are readily available through the Traffic Accident Surveillance and Analysis System (TASAS) but there are concerns about possible underreporting of accidents; moreover, it may be difficult to identify certain types of accidents of interest in performance monitoring, such as secondary accidents resulting from incidents. Measurement of traffic information accuracy requires development of procedures for verifying information disseminated to the public, and may prove to be rather labor intensive. Incident clearance times can be calculated from the California Highway Patrol (CHP) Computer Aided Dispatch system and in some cases may be available from incident logs kept by the district TMCs. Measurement of equipment status will require precise development of equipment status categories and development of computerized inventory and logging systems.

Traffic Data System Improvement Plans were prepared for Caltrans Districts 11 (San Diego) and 12 (Orange County). One objective in preparing the plans was to verify the practicality of the proposed performance measures. A second objective was to provide the two Caltrans districts with recommendations for improving their traffic data systems' ability to support performance measurement. The San Diego and Orange County districts were chosen because of their well-developed traffic data systems, their past involvement in supplying data for intelligent transportation systems (ITS) research, and their proximity to the researchers' home base.

The data system improvement plans document data system, describe existing data collection and management systems, evaluate the ability of existing systems to meet their

objectives, identify potential improvements and resources required to implement them, and state the districts' priorities for actions to improve their traffic data systems.

The two districts proved to have similar approaches to traffic data collection and management, similar existing systems (although the one in Orange County is more fully developed than that in San Diego), and similar plans for system improvements.

Both existing systems rely heavily on single-loop detectors to provide traffic surveillance; both districts plan to eventually provide complete coverage of their urban freeway systems with loop-based surveillance systems. The Orange County district also has a fairly extensive video surveillance system, which it plans to expand; San Diego does not yet have video surveillance, but plans an extensive system. Both districts also plan to install fiber-optic communications systems as a part of the deployment of their video surveillance systems.

The Orange County district has recently installed a current-generation data display and management system developed by the district and the National Electronic Technologies (NET) Corporation; the San Diego district is in the process of installing a similar system. The NET software provides incident and equipment-status logging capabilities; it also provides data screening and repair algorithms for loop detector data that can contribute to data quality control and equipment-status monitoring. Both districts also have access to adequate accident and traffic volume data bases.

Traffic data systems in the two districts appear to be generally adequate to support the major performance measures identified in this study. Possible deficiencies include 1) the questionable accuracy of travel time estimates derived from loop detector data (especially single loop installations that do not measure speed directly), 2) inadequate staffing to support labor-intensive data collection activities such as the manual queue counts needed to estimate ramp delays, 3) and lack of staffing and institutional infrastructure to support evaluation studies, performance monitoring, and data quality control. In general, the two districts studied are committed to the provision of sophisticated traffic data collection and data management systems. At the same time, however, they do not necessarily have a clear vision of how to use the data to monitor performance, and they lack the organizational structure and staffing to carry out activities such as evaluation studies, performance monitoring, and data quality control. Consequently, successful performance measurement will require significant institutional changes.

Recommended actions by Caltrans and PATH to improve traffic-related performance measurement include the following. Recommendations are listed in order of priority.

1. Caltrans should develop a policy for evaluation of investments in TMC functionality. A recommended policy is presented in Appendix C. Caltrans will need to refine this policy and make management decisions about whether and how to implement it.



2. Caltrans should explore arrangements for staffing evaluation studies. Since Caltrans will probably not be able to staff evaluation studies internally, appropriate contractual arrangements should be identified.
3. Caltrans or PATH should sponsor research to compare loop-detector-based travel time estimates with actual travel times.
4. Caltrans TMCs should develop quality control systems for traffic information.
5. Caltrans should develop a plan for monitoring traffic system performance. A proposed traffic monitoring system is discussed in Appendix D.
6. Caltrans or PATH should sponsor research concerning the feasibility of relating incident and accident data bases.
7. PATH should continue to conduct research on non-loop-based measures of travel time.
8. Caltrans should consider extending coverage of traffic surveillance systems; however, major expansion of the surveillance system *for the sole purpose of monitoring traffic system performance* should be postponed pending results of research comparing measured travel times with those estimated from loop-detector data and development of a performance monitoring plan.
9. Caltrans should develop data reduction and display software for a performance monitoring system once specific needs are identified.

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## 1. SCOPE AND OBJECTIVES

This report discusses issues and techniques related to performance measurement for traffic management systems. It documents the results of a study of performance measurement for California Department of Transportation (Caltrans) Transportation Management Centers (TMCs). This project was primarily concerned with the urban freeway system, and did not explicitly consider other portions of the highway system or non-Caltrans efforts such as local TMCs. Nevertheless, some of its findings may also be applicable to other kinds of traffic management systems.

Project objectives were to:

1. Analyze performance measurement requirements associated with Caltrans TMCs.
2. Identify and assess the feasibility of data collection and management activities required to support TMC performance measurement.
3. Recommend specific actions by Caltrans and PATH that will facilitate performance measurement.
4. Propose specific Traffic Data System Improvement Plans for two Caltrans districts.

Project results are documented in this report and in two working papers (1,2). One working paper was an interim report on the first year of research. It discusses the study's direction and scope, proposed measures of effectiveness, and preliminary proposals for actions by Caltrans and PATH to facilitate performance measurement. The other working paper documents traffic data system improvement plans for Caltrans TMCs in San Diego and Orange County.

## 2. BACKGROUND

As used in this report, *performance measurement* is defined as *the evaluation of a traffic system or some component thereof based on quantitative measures of system output, quality of service, environmental impact, or similar features*. In this sense, it is possible to measure the performance of the whole highway system (or some portion of it); a TMC; or a specific traffic management activity such as ramp metering, incident management, or traffic information dissemination.

The purpose of the research was to provide a comprehensive look at performance measurement needs for Caltrans TMCs and other Caltrans units involved in management of the urban freeway system. The existing Caltrans traffic management system grew up incrementally, with little formal evaluation of new investments. In many cases, the benefits of improved traffic surveillance, traffic control, and incident management

systems were regarded as obvious; the marginal costs of improvements appeared to be modest; and time and resources for evaluation studies were unavailable.

More recently, however, major investments in new surveillance and communications systems have been proposed for Caltrans TMCs, and Caltrans has been faced with diminished resources, especially in the area of staffing. This situation has led to increased interest in quantification of the benefits of TMCs and TMC functions. Meanwhile, PATH has been actively researching new methods for collecting traffic data that may be useful for performance measurement. Finally, there is concern that existing traffic data bases are not being fully exploited in the management and planning of the system. For instance, Caltrans has recently begun a statewide effort to monitor corporate performance indicators, some of which are related to traffic flow.

This study was intended to address current concerns and opportunities related to performance measurement by identifying situations in which quantitative measurement can contribute to valid assessment of performance; proposing specific measures of effectiveness (MOEs); evaluating the cost, validity, and accuracy of measurement techniques; assessing the existing availability of traffic information; and proposing improvements to traffic information systems for Caltrans TMCs in San Diego and Orange County.

Past research related to traffic management system performance measurement is fairly extensive. Although the term *performance* measurement has only rarely been used to describe such efforts (3,4), there is an extensive literature describing the evaluation of traffic management and data collection techniques (5-36). This literature raises a number of issues regarding the feasibility and accuracy of various measurement techniques. It also provides a starting point for defining measures of effectiveness for traffic management systems.

Other literature provides information about the scope of existing and future TMC activities and specific issues related to TMC organization and functioning. This literature is important in determining the scope and context of performance measurement for TMCs. Lo, Hall and Windover (37) assess existing capabilities of TMCs in California; related work includes in-depth studies of arterial and highway TMCs by Hall, Lo and Minge (38), emergency operations by Lo and Rybinski (39), and commercial vehicle operations by Hall and Chatterjee (40). These studies have been summarized by Hall, Lo and Minge (41). In addition, Booz-Allen and Hamilton (42) and Carvell et al (43) report on TMC organizational issues, and IVHS America (44), Joint Architecture Team (45), and Mitretek Systems (46) provide information about possible future TMC functions.

Finally, performance measurement concepts occur in the literature of business administration and public administration, where they are often linked to concepts such as strategic planning, total quality management, and organizational accountability (47-50). Poister (50) discusses application of these concepts to state departments of transportation. Performance measurement objectives emphasized in this literature include shifting

managerial attention from processes to outcomes, linking program objectives to outcomes through use of performance targets, monitoring program processes and trends, guiding resource-allocation decisions, and improving communication with elected officials and the public. Most of these objectives apply to traffic-related performance measurement. In addition, this literature discusses a number of issues related to the feasibility, institutional acceptability, and validity of performance measurement that apply to traffic-related performance measurement.

### **3. METHODOLOGY**

The overall project was organized into two phases. The first phase involved identification of performance measurement issues and measures of effectiveness (MOEs) for traffic management systems. Specific activities included refinement of project objectives and priorities through discussions with PATH and Caltrans personnel, a literature survey, an analysis of proposed MOEs for traffic system and TMC performance, and the identification and prioritization of specific actions intended to improve performance measurement. The second phase involved preparation of data system improvement plans for TMCs in San Diego and Orange County (Caltrans Districts 11 and 12). The data system improvement plans were intended primarily as a check on the practicality of implementing specific performance measures identified in the first phase of the project. They were also intended to serve as a basis for implementation of improved performance measurement systems in these two districts.

An initial task was to refine the direction and scope of the project based on input from PATH and Caltrans representatives. Suggestions were received through meetings, discussions with individuals, and review of project documents. An initial meeting with PATH and Caltrans Office of New Technology and Research representatives was held in January 1996 to review the scope of the project. On the basis of this meeting and subsequent discussions, it was decided to seek input from Caltrans traffic management personnel at a session of a Caltrans Traffic Engineers Conference held in Sacramento in March 1996. Following this meeting, a brief summary of the discussion and a proposed set of research priorities for the project were distributed to Caltrans and PATH representatives for their review.

Following this, objectives of specific TMC functions were identified based on a literature survey and discussions with Caltrans and PATH representatives. Potential MOEs based on these objectives were also proposed and analyzed in terms of their cost-effectiveness. Analysis involved preparation of a detailed analysis sheet for each proposed MOE. Appendix A presents one of these as an example of the format used in the analysis. Based on these detailed analysis sheets, summary analyses were prepared for what were considered to be the most important candidate MOEs. These summaries were distributed to the PATH and Caltrans representatives for review.

After the initial analysis of potential MOEs was concluded, specific actions by PATH or Caltrans that might improve performance measurement were identified and prioritized.



Priorities were based on technical feasibility, institutional feasibility, and cost-effectiveness. This list was also distributed to the PATH and Caltrans representatives for review. Final versions of the MOE analysis summaries and the priority action list were then prepared, based on feedback from Caltrans and PATH representatives and further research related to details of cost, feasibility, and progress by Caltrans in implementing new traffic information systems. MOE summaries are documented in Appendix B. The action priorities form the basis for the recommendations in this report; a preliminary version is also documented in a working paper (1).

In the project's second phase, data system improvement plans were prepared for the Caltrans districts in San Diego and Orange County. Development of data system improvement plans involved identification of data system objectives related to performance measurement, identification of data required to meet these objectives, documentation existing traffic data collection and management systems, evaluation of the ability of the existing systems to support traffic data system objectives, identification of potential improvements and the resources required to implement them, and documentation of the districts' priorities for actions to improve their traffic data systems.

#### **4. PERFORMANCE MEASUREMENT REQUIREMENTS**

One project objective was to analyze performance measurement requirements for California TMCs. This analysis addressed the questions of what needs to be measured and why. It involved identification of performance measurement *objectives*, the *objects* of performance measurement (that is, the things whose performance is measured), appropriate *study designs* for performance measurement, *measures of effectiveness*, and *measurement techniques*. This section analyzes the interrelationships among objectives, objects, and study designs to identify performance measurement applications that are likely to be both useful and feasible; the following section discusses specific measures of effectiveness and measurement techniques

##### **4.1 Performance Measurement Objectives**

Goals of performance measurement include rationalization of financial decisions related to the traffic management system, monitoring of system performance, and support of research. Specific objectives include:

- *Evaluation of investments* or disinvestments in TMCs or TMC functions.
- Rationalization of the *allocation of operating budgets* to TMCs or TMC functions.
- *Monitoring* to identify traffic system and traffic management system changes that require a response.

- *Reporting* to inform elected officials and the public about system status and agency performance.
- *Research* to advance theoretical understanding of traffic phenomena and the traffic management system.

## 4.2 Performance Measurement Objects

The objects of performance measurement include the following:

- The overall highway traffic system.
- TMCs and other Caltrans units involved in traffic system management.
- TMC functions.

Existing TMC functions include the following:

- *Ramp metering.* Operation of ramp metering systems.
- *Incident management.* TMCs are involved in this in two ways. In the case of routine incidents, they are responsible for providing traveler information and assisting with traffic control. For major incidents, they may also be involved in removing the incident and restoring roadway capacity to normal. In several of the larger districts, this is accomplished through Traffic Management Teams, made up of TMC personnel and representatives of other Caltrans units. In either case, the TMC interacts with agencies providing emergency services, such as the California Highway Patrol (CHP) or the local fire department.
- *Traveler information.* TMCs broadcast traveler information directly by means of changeable message signs (CMSs) and highway advisory radio (HAR). Some of them also supply traffic data to private-sector providers such as commercial radio stations and sponsors of World Wide Web pages.
- *Motorist Assistance.* Some TMCs are involved in providing motorist assistance by means of freeway service patrols (FSPs).
- *Data collection, management, and dissemination.* TMCs are usually involved in the collection, management, and dissemination of traffic data that is used for planning (and possibly other purposes) by other Caltrans units and other public agencies.

The scope of future TMC functions is the subject of continuing discussion and planning. The National ITS Architecture envisions a number of different kinds of “centers,” whose function is to collect and store transportation information (**45**). Existing TMCs focus on

traffic management, which is one of these functions. Future TMCs might incorporate additional functions but are more likely to exchange information with independent centers focused on functions other than traffic management. Current discussions about the future scope of Caltrans TMCs focus on issues of coordination, standardization, and interoperability. This focus makes it likely that the quality of information provided by TMCs to external users will be an increasingly important performance measurement issue, but unlikely that future TMCs will be involved in entirely new functions.

### **4.3 Study Designs**

In most cases, performance measurement proceeds by measuring some feature of the performance of the traffic system (such as travel time or accident rate) and using this to infer the performance of some part of the traffic management system (for instance, a TMC or TMC function). Performance measurement study designs provide the logical link between the measured performance of the traffic system and the inferred performance of the traffic management system. A major issue in such study designs is how to separate the effect of the performance of the object of the study from the effects of external circumstances.

Two basic types of study are possible. These are *longitudinal studies*, in which data is collected over time at a single location, and *cross-sectional studies*, in which data is collected simultaneously at a number of locations. Longitudinal studies are appropriate where external circumstances do not vary significantly over time, and cross-sectional studies are appropriate where they do not vary significantly with location. Longitudinal study designs are more appropriate than cross-sectional ones for most applications of performance measurement to traffic management systems. External circumstances such as travel demand patterns, the physical configuration of the highway system, bottleneck capacities, vehicle fleet composition, and driver population characteristics tend to vary a great deal with location, but may be relatively stable over short periods of time. Consequently, carefully-designed before-and-after studies are usually the best way to isolate the performance of particular features of the traffic management system.

### **4.4 Relationships Among Objectives, Objects, and Study Designs**

Table 1 presents an analysis of the interrelationship among performance measurement objectives, objects, and study designs. For most combinations of objective and object, longitudinal studies are appropriate. In the case of budget allocation decisions, however, the problem is inherently cross-sectional. Even so, longitudinal studies are indicated as appropriate for budget allocations to TMC functions, since in this case, if monetary benefits can be calculated or the measures of effectiveness of different functions are the same, it is possible to conduct a longitudinal study of each function and compare the results.

**Table 1. Relationships Among Objectives, Objects, and Study Designs.**

Objective	Object		
	Traffic System	TMC	TMC Functions
Evaluate Investments	Longitudinal	Longitudinal	Longitudinal
Budget Allocations	N/A	Cross-sectional	Longitudinal
System Monitoring	Longitudinal	Longitudinal	Longitudinal
Reporting	Longitudinal	Longitudinal	Longitudinal
Research	Longitudinal	N/A	Longitudinal

There are two important situations in which performance measurement may not be feasible. The first of these is where the evaluation problem is inherently cross-sectional but external circumstances vary significantly by location. This applies particularly to comparisons of the performance of different TMCs for purposes of allocating operating budgets. The second is where longitudinal studies are otherwise appropriate, but so much time has elapsed that the assumption that there is no significant variation in external circumstances with time is invalid. This applies to attempts to quantify the benefits of TMCs or TMC functions that have been in place for a number of years, even if “before” data are available. It is also a concern for studies comparing incident or accident rates where random variation in the data is so great that a period of several years is required to provide a reasonably precise estimate. It is also impossible, of course, to conduct longitudinal studies where no “before” data exist.

The foregoing analysis suggests that two basic types of performance measurement are feasible. The first involves before-and-after evaluation studies of specific traffic management actions, such as investment in new or expanded facilities or initiation of new operating strategies. These actions have expected results, and the purpose of the studies is to confirm these results. The second involves routine monitoring of traffic data and is intended to identify any unexpected deviations from normal operation that may result from changes in travel patterns, deterioration of facilities, managerial inattention, lack of maintenance, or similar causes. Traffic monitoring is also the basis for reporting system status to elected officials and the public. Results of both types of performance measurement are useful for research purposes. Requirements for these two types of performance measurement studies are discussed in detail in Appendices C and D.

## 5. MEASURES OF EFFECTIVENESS

A second project objective was to identify and assess the feasibility of data collection and management activities required to support TMC performance measurement. In order to analyze data collection and management requirements, it was necessary to identify measures of effectiveness for TMCs and TMC functions.

A measure of effectiveness is a *quantitative measure that is intended to express the degree to which an objective is met*. Proposed MOEs were identified through analysis of the objectives of the highway system and of the TMCs. In addition to MOEs identified by the research team, a number of specific MOEs were suggested by Caltrans representatives who attended a session on measures of effectiveness at the Caltrans Traffic Engineers Conference in March 1996. Proposed MOEs were analyzed to determine their potential value, feasibility, and cost-effectiveness. The discussion that follows identifies objectives, defines MOEs, discusses measurement techniques and issues, and provides a qualitative assessment of the cost-effectiveness of the major MOEs.

### 5.1 Objectives

Objectives of the freeway system that are directly related to traffic management activities include:

- *minimization of congestion*
- *minimization of accident rates, and*
- *minimization of environmental impacts*

Achievement of these objectives is affected by a number of external circumstances, the most obvious of which is *traffic demand*. In addition, *TMC workload* needs to be considered in assessing TMC performance, since it impacts the extent to which the TMC can respond to traffic system management needs.

TMCs contribute in a number of ways to achieving the objectives of the overall system. Some TMC functions are intended to contribute directly to objectives such as reducing congestion or accident rates. In other cases, TMCs provide more general support to Caltrans and the highway system, for instance by improving public relations or providing planning data. Existing TMC functions were discussed in Section 4.2. They include:

- Ramp metering.
- Incident management.

- Traveler information.
- Motorist Assistance.
- Data collection, management, and dissemination.

Each of these functions has its own specific objectives. These are as follows:

- *Ramp Metering.* Commonly recognized objectives of ramp metering are *reduction of delay and congestion, reduction of accident rates, and smoothing of flow* at on-ramp junctions by breaking up platoons of ramp vehicles. The last objective is satisfied by almost any metering installation, and is of little interest in performance measurement. Possible mechanisms by which ramp metering may reduce delay include 1) diversion of traffic around a bottleneck; 2) a possible small increase in bottleneck capacity if flow breakdown at the bottleneck can be prevented; and 3) control of freeway queues so as to prevent interference with exits upstream of the bottleneck. Ramp metering is believed to reduce accident rates by reducing the amount of congested traffic on the freeway, since accident rates tend to be higher in congested traffic than in uncongested traffic.
- *Incident Management.* Objectives associated with the overall process of incident management are to reduce the amount of time required to clear incidents, minimize delay, reduce the number of secondary accidents, and provide public information. Incident response duties are shared by Caltrans, the California Highway Patrol (CHP), and other emergency-service agencies. TMCs play a major role in the clearance of major incidents, but otherwise are mostly concerned with providing public information and traffic control. Objectives relating directly to Caltrans' role in incident management include *reduction of the time required to clear major incidents, reduction of delay and secondary accidents* for all incidents, *and provision of public information.*
- *Traveler Information.* Objectives associated with TMC traveler information functions are to *reduce accident rates* by providing early warning of incidents or other hazardous conditions, *reduce delay and congestion* by diverting traffic around incidents and other sources of congestion, and *improve public relations* by providing news about traffic conditions.
- *Motorist Assistance.* Motorist assistance services in the form of FSPs are provided by some California TMCs. Objectives of FSPs are 1) to *reduce delay and congestion* by quicker removal of stalled vehicles, accidents, and other incidents and 2) to *improve public relations* by providing assistance to motorists in distress.

- *Data Collection, Management, and Dissemination.* Because they manage ramp metering and traffic surveillance systems, TMCs are a primary source of automatically-collected traffic data used for planning purposes by other Caltrans units, metropolitan planning organizations (MPOs), and local governments. The objective related to this function is to *provide traffic data for planning purposes.*

## 5.2 Potential Measures of Effectiveness

Measures of effectiveness related to these objectives are as follows:

- *Travel Time and Related Measures.* Travel time is the amount of time required for a vehicle to cover a specified distance. Related measures, several of which can be derived from travel time, include average speeds, delays, and various measures of the extent of congestion. Measures of the extent of congestion normally involve determining the number of freeway miles and hours for which speeds are below a stated threshold. Alternatively, the extent of congestion can be represented as the fraction of time (for a particular location and time of day) that speed is below the threshold. In order to provide a useful measure of congestion, travel times need to be available for relatively short sections of roadway and relatively short time intervals.
- *Traffic Volumes and Related Measures.* A *traffic volume* is the number of vehicles passing a point counted during a specified time interval. Traffic counts are also commonly expressed as daily or hourly *flow rates*, and may be classified according to type of vehicle (passenger cars, trucks, etc.) In addition, *travel* may be measured in vehicle-miles for some specified time interval.
- *Ramp Delay.* Ramp delay is increased travel time due to queuing on metered ramps.
- *Accident Rates.* The accident rate consists of the number of accidents divided by total travel, expressed as vehicle miles of travel (VMT) or a similar measure. In order to be useful for certain types of performance measurement, rates for specific types of accidents must be available, and they must be available for short sections of roadway.
- *Air Pollution Concentrations.* Air pollution concentrations are concentrations (in parts per million or similar units) of specific air pollutants or air pollution indicators, such as ozone, nitrogen oxides, or carbon monoxide. Air pollution concentrations may be measured over areas of various sizes, depending on the situation.
- *Energy Consumption.* Energy consumption may be measured in terms of gallons of fuel consumed or similar measures.
- *Incident Clearance Time.* Incident clearance time, strictly speaking, is the time elapsing between the occurrence of an incident and the time that the roadway is completely restored to its normal condition. Because it is often difficult to determine

exactly when an incident occurred, a better working definition is the time elapsing between the time the incident is reported and the time it is completely cleared.

- *Incident Count.* The incident count is a tally of the number of incidents. To be useful for performance measurement, incident counts need to be classified as to incident type, facilities or geographical area involved, and time period.
- *Information Accuracy.* Information accuracy is the fraction of messages of a particular type that can be verified.
- *Motorists Assisted.* Motorists assisted is the number of motorists receiving assistance from an FSP or similar service, classified according to geographical area and time period.
- *Customer Satisfaction.* Customer satisfaction involves some sort of subjective rating of the quality of a service such as FSP assistance. It is usually determined by means of opinion surveys.
- *Equipment Status.* Equipment status is the fraction of equipment functioning properly, as opposed to that either not functioning or producing erroneous data.

Table 2 shows the relationship between the measures of effectiveness and the various performance objectives of the freeway system and the TMCs. As can be seen from the table, a single MOE is often used to evaluate several objectives.

Not all the MOEs listed above are of equal significance. In selecting MOEs for further analysis, several were eliminated because they relate to very narrow activities or because they are only tangentially related to the activities of TMCs. Among these are the MOEs specifically related to the FSPs (motorists assisted and customer satisfaction) and those related to the environmental impacts of the system (air pollution concentrations and energy consumption). In both cases, information is already being collected and its possible uses are fairly obvious. In addition, incident counts were eliminated from further analysis because they were felt to contribute in only a minor way to the overall assessment of freeway system and TMC performance. Detailed analysis of cost-effectiveness was carried out for the remaining measures, which are referred to as the *major MOEs for traffic system management*. These include:

- Travel time and related measures
- Ramp delay
- Traffic volumes
- Accident rates



**Table 2. Relationship Between Objectives and Measures of Effectiveness.**

Objective or Circumstance	Measure											
	Travel Time, etc.	Ramp Delay	Traffic Volume	Accident Rate	Air Pollution Concentration	Energy Consumption	Incident Clearance Time	Incidents Count	Information Accuracy	Motorists Assisted	Customer Satisfaction	Equipment Status
Overall System Objectives												
Minimize Congestion	x	x										
Minimize Accident Rate				x								
Minimize Environmental Impact												
Minimize Air Pollution					x							
Minimize Energy Consumption						x						
Ramp Metering Objectives												
Reduce Delay/Congestion	x	x	x									x
Reduce Accident Rate				x								x
Smooth Flow												x
Incident Management Objectives												
Reduce Clearance Time							x					
Minimize Delay/Congestion	x		x									
Prevent Secondary Accidents				x								
Provide Public Information									x			
Traveler Information Objectives												
Reduce Accident Rates				x								
Reduce Delay/Congestion	x		x									
Improve Public Relations									x			
Motorist Assistance Objectives												
Reduce Delay/Congestion	x											
Improve Public Relations									x		x	
Data Management Objective												
Provide Traffic Data for Planning									<b>X</b>			x
External Circumstance												
Travel Demand			x									
TMC Workload							x	x				

- Traffic information accuracy
- Incident clearance times, and
- Equipment status

### **5.3 Measurement Techniques and Issues**

Measures of effectiveness are useful only if it is possible to quantify them. The following section discusses measurement techniques for the major MOEs identified above. In some cases, several measurement techniques are available, and in these cases selection of the appropriate measurement technique may be an important issue.

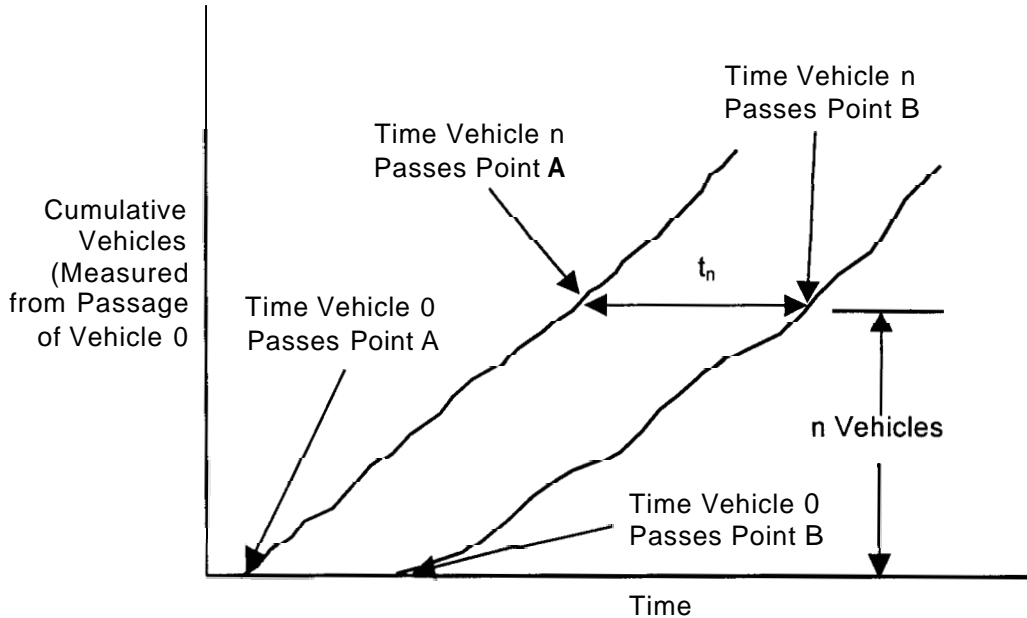
#### **5.3.1 *Travel Time and Related Measures***

Alternative approaches to determining travel times include estimating them from spot speeds, estimating them from cumulative flow distributions, and measuring them directly.

The first two techniques make use of loop detector data. In the first, it is assumed that the reciprocal of the average spot speed measured at a point is representative of the average travel time across some section surrounding the detector. Average spot speeds, in turn, may be measured directly by means of double loops, or may be estimated (with some loss of accuracy) from volumes and lane occupancies. This technique is subject to some inaccuracy due to errors in estimating or measuring spot speeds, but these are unlikely to be very significant where the object is to determine average travel times over comparatively long periods of time (five minutes or more) and to compare travel times across the same section for different periods of time. More serious errors result during periods when sections are partially congested, since speed at the point of measurement is not representative of the average speed across the entire section.

The second technique attempts to identify the time difference between cumulative flow curves at two different locations. If the time that a single vehicle passes both points can be identified, counts are perfectly accurate, and there is no traffic entering or leaving the roadway between the two locations, the cumulative counts can be used to determine the time that each successive vehicle passes each point. From this, average travel times may be calculated, although not the travel time of each vehicle, since vehicles will sometimes pass one another. Alternatively, if the number of vehicles in the section at time zero is known, the total travel time for all vehicles for any subsequent period is the time integral of the number of vehicles in the section or (by definition) the average number at any instant multiplied by the duration of the time interval. Division by the flow passing some point in the section gives the average travel time per vehicle. This technique is illustrated by Figure 1.

**Figure 1. Determination of Travel Time from Cumulative Vehicle Counts.**



Different versions of this second technique have been used in past performance measurement studies (1) and, more recently, in experimental work related to incident detection (28,35). The major advantage of this technique is that it can measure travel times across sections during periods when they are partially congested. Its disadvantages are that 1) it requires the externally-measured travel time of at least one vehicle (or alternatively, the number of vehicles in the section at time zero) in order to initialize the counts and 2) because the errors accumulate, even small biases in volume counts can lead to large errors in estimated travel time if the process is carried on long enough. If the process is initialized during periods of uncongested flow, it may be possible to make reasonable estimates of the initial conditions by generalizing spot speeds or occupancies. The second problem, however, is more difficult, and requires either frequent recalibration or sophisticated data filtering techniques to prevent large errors. Because of these difficulties, this technique must still be regarded as experimental.

In California, loop detector systems are present to some extent in most large metropolitan areas. Most of the existing detectors were installed either to provide real-time

surveillance, as a part of ramp metering systems, or to collect traffic volume data as a part of the traffic census program. Existing detector systems include both single-loop and double-loop installations, with single-loop installations predominating. The extensiveness of these systems varies significantly among the urbanized Caltrans districts.

The accuracy of loop detector data is potentially affected by various types of detector malfunctions. Recent research has found that detector malfunction rates are substantial, even if only “obvious” malfunctions are considered (36). Various data repair algorithms are available to provide estimates of missing (or obviously erroneous) data, but use of these detracts from confidence in the accuracy of measurement. Consequently, a high standard of maintenance for detectors and continuous monitoring of data quality are important where loop detector data are used to estimate travel times.

Direct measurements of travel times have traditionally been made with test cars, often those equipped with recording tachometers (so called “tach cars”). More recently, there have been proposals to measure travel times using relatively large fleets of privately-owned vehicles. One technique currently under investigation is use of probe vehicles; that is, vehicles equipped with some sort of on-board device (such as a transponder or a bar code) that can be read by a roadside device, thus establishing the location of the vehicle so that it to be tracked. A related technique which is also being investigated is vehicle identification-reidentification, in which vehicles may be recognized at more than one location, based on some characteristic. Identification-reidentification differs from use of probe vehicles in that in the case of identification-reidentification, no on-board device is necessary. The traditional identification-reidentification technique is to match license plate numbers; more recent versions have attempted to match radar spectra, color, or other features.

### **5.3.2 *Rump Delay***

At present, manual queue counts are the only way to measure queuing delay on ramps. Possible future techniques might involve some type of image processing.

### **5.3.3 *Traffic Volumes***

Traffic volumes are provided by loop detector systems. In California, traffic volumes are monitored as part of an ongoing traffic census effort. In addition, much more complete volume information is available for portions of the system where surveillance or ramp meter control detectors have been installed.

### **5.3.4 *Accident Rates***

Accident rates are currently available in California on just about any useful basis through the Traffic Accident Surveillance and Analysis System (TASAS) data base. TASAS is an accurate reflection of the accident reports filed for the state highway system, but probably

underrepresents accident rates due to underreporting of accidents. This is believed to be a particularly significant problem in the case of accidents involving property damage only. Also, the current TASAS format does not allow positive identification of secondary accidents resulting from incidents. TASAS allows identification of accidents for which “stop-and-go traffic” was listed as an associated factor, but does not currently distinguish between incident congestion and recurrent congestion.

Finally, in some cases it may be impractical to measure the relevant accident rates. For instance, in evaluating the effectiveness of HARs and CMSs, it might be useful to determine their effect on accident rates during periods when hazardous conditions exist. In order to evaluate the impact of such information on accident rates, it is necessary to compare accident rates, with and without the warning, in situations involving the hazard. Since hazardous conditions are fairly rare, and accidents under hazardous conditions even rarer, extended data collection periods are apt to be required. For this reason, it may not be practical to assess this aspect of CMS and HAR performance on a routine basis, although it might be the subject of research.

### **5.3.5 *Traffic Information Accuracy***

Information accuracy may be measured by verifying information released to the public or to third-party providers and calculating the fraction of messages that are accurate. In the case of loop detectors, equipment status is also an important indicator of data quality.

### **5.3.6 *Incident Clearance Times***

Information on incident clearance times is available from the CHP Computer Aided Dispatch (CAD) system and in some cases may also be available from incident logs kept by the district TMCs.

### **5.3.7 *Equipment Status***

Surveillance equipment status may be quantified as the fraction of equipment functioning properly, as opposed to that either not functioning or producing erroneous data. Measurement of equipment status requires precise definition of the various equipment status categories, an equipment inventory, and a logging system for keeping track of changes in equipment status.

## **5.4 *Cost-Effectiveness of MOEs***

Summaries of cost-effectiveness analyses for the major MOEs and measurement techniques are presented in an appendix. Table 3 presents a *summary* of the overall results of this analysis.

**Table 3. Cost-Effectiveness of MOEs and Measurement Techniques.**

		Effectiveness		
		High	Medium	Low
cost	High	Travel Time, Tach Car Manual Ramp Queue Counts	Traffic Info. Accuracy*	
	Medium		Equipment Status*	
	Low	Travel Time, Probe Vehicle* Accident Rates Traffic Volumes	Travel Time, Loop Detector Incident Clearance Time	
*Requires further development before implementation				

**6. CASE STUDIES: DATA SYSTEM IMPROVEMENT PLANS**

Another study objective was to propose specific Traffic Data System Improvement Plans for two Caltrans districts. The data system improvement plans were intended both as a check on the practicality of implementing specific performance measures identified in the first phase of the project and as a basis for implementation of improved performance measurement systems by Caltrans. The San Diego and Orange County districts were selected as sites for this activity. These particular districts were chosen for a number of reasons:

- The San Diego district has been a leader in developing ITS systems in California, particularly the automatic data-collection and management systems associated with traffic-responsive ramp meters.
- The Orange County district has taken the lead in developing and implementing the most recent generation of automatic data collection and display software, in collaboration with the National Electronic Technologies (NET) Corporation.

- Both districts have been the source of automatically-collected data that have been used in ITS research. Data from the San Diego district have been used in past research by San Diego State University on performance measurement and control strategies for ramp metering systems as well as research and development by Ball Aerospace and Technologies Corporation related to incident detection, freeway flow modeling, and traffic data collection and display systems. Orange County is the site of the Orange County Test Bed, and has been the site of a large amount of ATMIS research carried out by the University of California, Irvine and others, much of it under the auspices of PATH.
- Both districts are located close to San Diego State University, and the research team was already somewhat familiar with their data collection systems, particularly that of the San Diego district.

For both districts, the data system improvement plans:

- Set forth data system objectives related to performance measurement and identify data required to meet these objectives.
- Document existing traffic data collection and management systems, including traffic surveillance systems, traffic data management and display systems, traffic data bases, and the personnel required to manage, operate, and maintain the system.
- Evaluate the ability of the existing system to support traffic data system objectives.
- Identify potential improvements to the traffic data system.
- Identify resource requirements for implementing potential improvements.
- State the districts' priorities for actions to improve their traffic data systems.

The two data system improvement plans are documented in a working paper (2). A summary and comparison of the plans is presented here.

## **6.1 Summary of Plans**

Since both districts have similar approaches to traffic data collection and management are similar, the goals of the two systems are similar. In both cases, objectives are to support the following:

1. Evaluation of expansions or improvements to ramp metering systems and changes in ramp metering strategies.
2. Evaluation of incident management procedures.

3. Evaluation of motorist assistance services such as freeway service patrols (FSPs).
4. Congestion monitoring efforts.
5. Long- and short-range planning and management of the freeway system.
6. Quality control for traffic information disseminated to the public, other Caltrans units, and other public agencies.
7. Evaluation of TMC equipment availability

For the most part, both districts also collect similar types of data. There are significant differences, however, in the degree to which the two systems are developed. These include differences in the degree of geographical coverage, in approaches to the overall task of traffic surveillance, and in the sophistication of data collection and display software.

Both data collection systems are oriented toward real-time monitoring of traffic conditions, although both also have the capability of producing reports summarizing historical data. In both cases, traffic surveillance systems rely heavily on single loop detectors; the majority of these single-loop detector stations are used primarily for ramp meter control. In addition, a number surveillance stations (some involving double loops) have been installed in both districts, but controllers adapted to double loops are lacking. The Orange County surveillance system also includes a fairly extensive video surveillance system; to date, San Diego does not employ video surveillance, although an extensive system is planned.

Both districts maintain computerized loop-detector data bases and computerized incident logs, although the accessibility of data in the existing log for the San Diego district is limited by the difficulty of searching and sorting it. Both districts have access to an adequate accident data base through the statewide Traffic Accident Surveillance and Analysis System (TASAS).

Both districts have some current capability to provide for access to traffic data bases by external users.

At present, the traffic data system in Orange County is more fully developed than that in San Diego. First, Orange County's loop detector system provides nearly complete coverage of its freeway system. San Diego's system is much less complete, and a number of freeway segments that are believed to experience recurring congestion are not covered. Second, Orange County has recently installed state-of-the-art data management and display software that it developed in conjunction with NET Corporation. San Diego's current data management and display software is obsolete and is being replaced by a system similar to that in Orange County. Finally, San Diego has installed a number



of surveillance detector stations that are not currently useful because they lack counter and communications systems. When fully operational, these will provide spacings of 0.33 to 0.5 mile on several freeways; these compare with current spacings of 0.5 to nearly 2.0 miles in San Diego and 0.6 to 1.0 mile in Orange County.

Overall resource allocation to traffic data collection appears to be somewhat more generous in Orange County than in San Diego. In addition to the investment in a more extensive surveillance system and more up-to-date data management and display software, Orange County has been able to maintain long-standing data collection activities such as ramp queue counts, which San Diego has dropped due to resource constraints.

Table 4 summarizes and compares planned traffic data system improvements in the two districts. Proposed improvements were identified in consultation with representatives of the traffic management units of the two districts and were prioritized by the districts. The overall priority classification scheme had six levels. These were:

Level 1: District is already committed to this action; resources are available or action is already underway.

Level 2: District is committed to this action, but resources are not yet available.

Level 3: High priority, but district is not yet committed to this action.

Level 4: Medium priority.

Level 5: Low priority.

Level 6: The district does not want to pursue this action.

In actually rating proposed actions, however, the districts used only the first three levels.

As can be seen from the table, the planned systems will be very similar at full deployment. Many of the differences in the improvement plans result from differences in the degree to which the existing systems are developed. Both districts plan to provide complete coverage of their urban freeway systems for both ramp metering and detector surveillance systems. In addition, both districts plan extensive video surveillance systems and fiber-optics communications systems to support them. On the other hand, neither district has specific plans for conducting evaluation studies or providing performance monitoring, although both consider these activities to be important.

**Table 4. Planned Data System Improvement Actions**

Action	Status	
	San Diego	Orange County
Install NET Software	Level 1 (underway)	Completed
Install controllers and communications for existing loops	Planned as part of communications system deployment	N/A
Improve data access for external users	No specific plans	Level 1
Phase in 2070 controllers at double loop sites	Planned as part of communications system deployment	Level 2
Complete deployment of loop surveillance system	Level 2	Level 3
Deploy or extend CCTV system	Level 2	Level 2
Deploy fiber-optics communications system	Level 2	Level 2
Complete deployment of ramp metering system	Level 2	Level 2
Provide staffing for evaluation studies	Level 3	Level 2
Institute traffic data monitoring program	Level 3	Level 2
Institute traffic data quality control program	Level 3	Level 2
Restore or expand ramp queue counting program	Level 3	Level 3

The data system improvement plans also include estimates of resources required to implement particular actions, where these were available. These are omitted from Table 1 because the way actions were grouped together in projects was not consistent between the two districts. Overall the San Diego district expects to spend about \$81 million on deployment or expansion of the loop detector surveillance system, the video surveillance system, the ramp metering system, and the fiber-optics communications system. The Orange County district expects to spend about \$34 million on similar improvements. See Appendices A and B for details.

## 6.2 Lessons Learned

Development of the Traffic Data System Improvement Plans provided an opportunity to evaluate the practicality of the performance measures identified in the first phase of the project. Evaluation of major measures of performance was as follows:

- *Travel time and related measures.* Neither district is pursuing anything other than loop-detector based methods for measuring travel times, speeds, delays, or similar quantities. At present, neither district is capable of measuring speeds directly by means of double loops. Both have installed some double loop stations, but currently use only one loop at these stations due to lack of adequate controller equipment. Full use of double-loop stations requires installation of Model 2070 controllers. Installation of these is on hold, pending resolution of software and incident detection issues and allocation of resources. Meanwhile, research related to the accuracy of loop-based methods for estimating speeds and travel times from loop detector data remains a priority. Specific objectives of this research should be to 1) determine the most accurate methods for estimating speeds and travel times from loop detector data (especially single-loop data) and 2) quantify the errors resulting from the use of different methods.
- *Ramp delay.* Manual queue counts remain the only practical way to estimate ramp delay. Because this activity is labor intensive, it tends to be given low priority. The San Diego district has discontinued ramp queue counts due to resource constraints. The Orange County district continues to conduct routine ramp queue counts, but the number and frequency of counts is considerably less than that recommended in Appendix B.
- *Traffic Volumes.* Traffic volumes are available on a comprehensive basis in both districts through the Traffic Census program. In Orange County, where the coverage of the detector surveillance system is virtually complete, much of the traffic census data is supplied by the traffic data system. Also, because of the virtually complete coverage, traffic volumes may be obtained at many more locations, and at much higher frequencies than is common in the Traffic Census program. In the San Diego district, detector coverage is not complete. Consequently, the spacing and frequency

with which traffic volumes are available vary a great deal, depending on whether a given roadway segment is covered by the detector surveillance system.

- *Accident rates.* In both districts, very complete accident rate information is available through the TASAS program. There is a time lag in the availability of accident rate data, however, and its comprehensiveness may be limited due to non-reporting of accidents. Non-reporting is a less serious problem on freeways than elsewhere because of the high visibility of accidents and the high probability of response by the CHP, but presumably it does occur to some extent.
- *Traffic information accuracy.* Both districts have, or will soon have, the capability of automatically detecting and recording certain types of loop-detector data errors. Verification of the accuracy of other types of data commonly disseminated will require manual checking. The costs of doing this appear to be modest (from 0.5 to 1.0 PY/year of technician time), but the requirement for additional staffing runs counter to the trend in Caltrans of reducing staffing.
- *Incident clearance times.* Both districts keep computerized incident logs. Those produced with the NET software (currently installed in Orange County and under development in San Diego) should be adequate for establishing incident clearance times (provided the necessary data are recorded in the log) and are recorded in a data base format that allows convenient sorting, searching, and other types of analysis. Actual calculation of clearance times from the incident logs will require some additional staffing, and so far, neither district is committed to this.
- *Equipment status.* The NET software currently installed in Orange County and under development in San Diego provides for equipment status logs. Certain types of failures for the loop detector system will be recorded automatically. Other equipment status information may have to be entered manually. To date, neither district is committed to producing equipment status reports or providing staffing to do manual data entry.

Development of the traffic data system improvement plans also provided an opportunity to reconsider tentative action priorities that had been proposed as part of the first phase of the study (I). For the most part, the experience of producing the data system improvement plans confirmed the appropriateness of these proposals, which are the basis for the recommendations in this report. In two cases, however, it was discovered that recommended actions (related to the development of incident and equipment-status logging capabilities) had already been taken in the development of the NET software package. Other action proposals were modified to reflect the fact that Caltrans districts will probably need to contract out evaluation studies, and possibly other performance measurement functions such as preparation of performance monitoring reports. It also became clear that the districts were less ready than expected to implement performance monitoring systems. A major problem was a lack of clarity as to who would use the

information and how. Some of this uncertainty appears to result from a lack of communication between traffic operations units and potential data users such as transportation planners.

Other important lessons learned in the course of preparing the traffic data system improvement plans had to do with the ability of the two districts to carry out performance measurement. In both cases, the districts are in the process of installing sophisticated traffic data collection and management systems. When fully deployed, these systems should be adequate to support the quantification of the performance measures recommended in this study. The existence of sophisticated data systems does not necessarily mean that these districts are prepared to do performance measurement, however. The data systems are primarily intended to support ramp metering and incident management functions; the collection of traffic data is really a byproduct of these activities. Neither district appears to have a clear vision of how to monitor traffic performance; and, at present, neither has the staffing or organizational structure to carry out activities such as performance monitoring, evaluation studies, and traffic data quality control. Also, they lack the staffing to undertake labor-intensive data collection, even where it is necessary to give a balanced and accurate picture of system performance. Consequently, successful performance measurement will require significant institutional changes. These include development of a clear vision of the potential benefits of performance measurement, better communication among units producing and using traffic data, provision of at least some additional staffing, and resolution of legal and political issues related to contracting for professional services.

## **8. CONCLUSIONS**

1. The most appropriate applications of performance measurement to traffic management systems are in the areas of a) evaluation of operational changes or investments in TMC functionality and b) continuous monitoring to detect changes in traffic system performance that require response.
2. Due to the difficulty in separating the effects of TMC performance from those of external circumstances, performance measurement is not an appropriate means of establishing the overall benefit of TMCs or comparing the performance of different TMCs.
3. In most cases, the appropriate study design for evaluations of operational changes or investments in TMC functionality will be before-and-after comparisons. These evaluations do not require continuous collection of data. They do require a firm policy requiring evaluations to be conducted, timely availability of data collection infrastructure, and appropriate staffing or contractual arrangements.
4. A major barrier to successful performance monitoring for the traffic system is a lack of clarity as to who will use the information and how. In some cases, this problem is complicated by lack of communication between Caltrans units involved in traffic

operations and those involved in transportation system planning or other functions that could benefit from performance monitoring.

5. The most important measures of effectiveness for traffic management systems are travel time and related measures, ramp delay, traffic volumes, accident rates, traffic information accuracy, incident clearance times, and equipment status.
6. There are a number of unresolved issues related to the measurement of travel times and related measures such as speed or delay. Existing traffic surveillance systems are almost entirely based on induction loop detectors, and most detection stations in these systems involve single-loop detectors, which do not measure speed directly. Several techniques have been proposed for establishing travel times from loop detector data, but, to date, their relative accuracy has not been clearly established. Also, research is underway on non-loop-based travel time measurement techniques, such as probe vehicles and identification-reidentification techniques, but none of these is currently ready for widespread deployment.
7. Existing TMCs in San Diego and Orange County provide loop-detector-based traffic surveillance systems, data collection and display software, historical data bases, incident and equipment status logging capabilities, and data access for external users. The current generation of data collection and display software recently installed in Orange County and scheduled for installation in San Diego appears to be adequate to support almost all performance measurement activities recommended by this study. Geographical coverage of the San Diego traffic surveillance system is incomplete. Actions that may improve performance measurement capabilities in these districts include extension of the coverage of the traffic surveillance system, improved communications systems, restoration or expansion of ramp queue counting programs, and provision of institutional arrangements for evaluation studies, traffic data monitoring, and traffic data quality control.
8. Although the San Diego and Orange County districts are in the process of developing sophisticated traffic data systems, they are not yet fully prepared to carry out performance measurement functions. Neither district appears to have a clear vision of how to monitor traffic performance; and, at present, neither has the staffing or organizational structure to carry out activities such as performance monitoring, evaluation studies, and traffic data quality control. Also, they lack the staffing to undertake labor-intensive data collection, even where it is necessary to give a balanced and accurate picture of system performance. Consequently, successful performance measurement will require significant institutional changes.

## **9. RECOMMENDATIONS**

Recommended actions by Caltrans and PATH to improve traffic-related performance measurement are listed below in rough order of priority. Priorities are based on the

expected benefit of the recommended actions, their cost, and the time required to implement them.

1. Caltrans should develop a policy ‘forevaluation of investments in TMC functionality. Much of the motivation for measuring TMC performance is related to the need of Caltrans management to justify TMC budgets and investments in specific TMC functions. In most cases where specific investments are involved (for instance, new or expanded efforts in various TMC functional areas) the most appropriate way to determine whether the project is producing its expected results is through carefully-constructed before-and-after studies. A policy is needed to spell out what types of studies should be undertaken, to ensure that appropriate data is gathered to support the “before” part of the evaluation study, and to ensure that adequate resources are allocated to support the evaluations. A recommended policy is presented in Appendix C. Caltrans will need to refine this policy and make management decisions about whether and how to implement it.
2. Caltrans should explore arrangements for staffing evaluation studies. Based on input from the San Diego and Orange County districts, Caltrans will probably not be able to staff evaluation studies internally. One possible model for staffing such studies is for Caltrans Headquarters to enter into a multi-year statewide contract with either a consulting firm with local offices throughout the state, or with PATH, which would subcontract with local universities. In the event of such an arrangement, local districts would issue task orders against the statewide agreement for individual evaluation studies. In the absence of a statewide contract, individual districts may need to enter into contracts with local consulting firms or universities.
3. Caltrans or PATH should conduct research to compare loop-detector-based travel time estimates with actual travel times. This research should identify or generate proposed techniques for measuring travel time from loop detector data, evaluate their feasibility and relative accuracy, and recommend the most appropriate techniques for performance measurement application. It should be noted that performance measurement applications differ from real-time surveillance applications in that post-processing of data is possible. Accuracy may be evaluated by comparing estimated travel times with travel times measured by probe vehicles. The 1-880 data base appears to be appropriate for this research.
4. Caltrans TMCs should develop quality control systems for traffic information. Information accuracy has been identified as a major concern by Caltrans personnel. Currently, there is no organized way of monitoring the accuracy of traffic information. Information quality-control systems are expected to vary from district to district depending on the types of information disseminated. Development of a quality-control systems will require 1) identification of all types of information being disseminated, the source of each type of information, and the means of dissemination; 2) establishment of procedures for checking the accuracy of each type of information; 3) establishment of policies regarding the frequency with which information is to be

verified; 4) establishment of procedures for reporting statistics related to information quality; and 5) identification of personnel to monitor information quality.

5. Caltrans should develop a plan for monitoring traffic system performance. Data currently collected by TMCs forms an important resource that could be used to give early warning of changes in the performance of the traffic system that require response. At present, this resource is not really being exploited in a systematic way. There is ongoing monitoring of traffic volumes and accident statistics, but little attempt to monitor other important aspects of traffic system performance such as trends in travel times or incident rates other than accident rates. In addition, periodic review of information such as congestion patterns (that is, the times and locations of occurrence of congested traffic) may provide valuable information. In order to improve performance monitoring, a comprehensive system for periodically reviewing traffic data and presenting the results to the responsible decision makers needs to be developed. The monitoring system plan should identify staffing needs and needs for improved data reduction and display software, and should develop formats and schedules for periodic monitoring reports. Requirements for a routine performance monitoring system are discussed in Appendix D.
6. Caltrans or PATH should conduct research concerning the feasibility of relating incident and accident data bases. One major measure of effectiveness for TMC incident management is the rate of secondary accidents caused by incident congestion. This measure is important because a major contribution of Caltrans TMCs to the management of routine incidents is provision of traffic control and motorist information, both of which are intended (in part) to improve safety in the area upstream of the incident. In order to measure this rate it is necessary to identify accidents in which incident congestion is a contributing factor. At present, it is possible to use the TASAS accident data base to identify accidents associated with congested traffic, but it is not possible to determine whether the congestion was caused by a previous incident. In addition, most accidents presumably are recorded in incident logs, but there is no cross-referencing system. In order to establish one, it will be necessary to establish the connection between entries in the incident log and specific accident reports. Research is needed to determine whether it is possible to 1) identify which incident log entries apply to given accidents, and 2) to identify accidents associated with incident congestion as opposed to recurrent congestion. In both cases, the research involves comparing information in accident records with that in the incident log, and possibly with other information such as speed estimates from the loop detector system; consequently, it would be convenient to conduct a single research project to settle both issues.
7. PATH should continue to conduct research on non-loop-based measures of travel time. Non-loop-based techniques for determining travel time, such as probe vehicles and identification-reidentification techniques, have the potential to provide more accurate travel time data than can be estimated from loop detector systems. These



techniques are the subject of ongoing research. Further work is required to determine the best techniques and to estimate the costs of implementing them. Ongoing research should be continued and coordinated with research comparing measured travel times with those estimated from loop detector data.

8. Caltrans should consider extending coverage of traffic surveillance systems. If a performance monitoring system is instituted, expansion of the traffic surveillance system may be needed to provide section-by-section travel time estimates on a geographically-comprehensive basis. The benefit in terms of increased information is expected to be greatest for sections with no existing detector systems and either recurrent congestion or high incident rates. Some expansion of the existing traffic surveillance systems is expected to take place as ramp meter and real-time surveillance systems are expanded. Major expansion of the surveillance system *for the sole purpose of monitoring traffic system performance* should be postponed pending results of research comparing measured travel times with those estimated from loop-detector data and development of a performance monitoring plan.
9. Caltrans should develop data reduction and display software for the performance monitoring system. It is expected that traffic system performance monitoring will require additional data reduction and display software, and that needs for such software will be identified as part of the performance monitoring system planning effort recommended above (recommendation 4). A second stage in the development of the performance monitoring system will be the actual development of this software.

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## APPENDIX A

### SAMPLE DETAILED ANALYSIS SHEET FOR MEASURES OF EFFECTIVENESS

**Function:** *General*

**Objective:** *Reduce Congestion*

**MOE:** *Travel Time*

**Data Requirements:**

Travel time by section (including freeway ramps) and time of day.

**Data Sources:**

Loop detector data

- Ramp meter controllers
- Surveillance detectors

Travel time runs with tach cars

Probe cars (possible future data source)

Hand queue counts for ramp delays

**Analysis Issues:**

Short-run variation in average travel times and appropriate sample sizes.

Lack of comprehensive coverage of freeway system for automatic data sources such as loop detectors.

Lack of coverage of freeway ramps and most non-freeway facilities by automatic data sources.

Consequently, need to combine sources with very different amounts of data; accuracy and representativeness of data from non-automatic sources.

If probe vehicles used, how to ensure that their travel times are representative of traffic in general. Need to be vehicles that normally travel at the same speed as other traffic, and need to be dispersed fairly evenly through the traffic stream.

Aggregation of point speed data to produce estimates of travel times across sections.

**Other concerns:**

Accuracy of loop detector data.

Possible biases in converting from volume and occupancy to speed for single loop detectors.

Location of detectors for ramp meter controllers is normally just upstream of ramp junction. This may bias results where data from ramp metering system is principal source.

## APPENDIX B

### COST-EFFECTIVENESS ANALYSIS SUMMARIES FOR MAJOR MEASURES OF EFFECTIVENESS AND MEASUREMENT TECHNIQUES

#### *Travel Time for Mainline Freeway Segments, Estimated from Loop Detector Data*

- **Requirements for Implementation:** Current loop detector systems provide partial coverage in urban areas; extensiveness varies considerably by region. More extensive coverage requires installation of loops, counters, and communications systems. Also, existing software may report estimated speeds rather than travel times. Minor extensions of existing software may be required to provide data in the desired form, and, more importantly, decisions about the level of aggregation are needed. Depending on these decisions, new data reduction software may be required. Research to better determine the relationship between the spot speed estimates produced by loop detector systems and travel times across extended sections (especially under congested conditions) is needed to better establish the accuracy of this technique.
- **Technical Feasibility:** Currently deployed
- **Potential Value:** Travel time is one of the fundamental measures of system performance. The same basic data can also be reduced to estimate delay and average speeds on a section-by-section basis. Loop-based travel time estimates are not entirely accurate. If travel time is estimated from spot speeds, errors may result from incorrect adjustment of detectors. Biases may also result from incorrect estimates of vehicle length in the case of single-loop installations and from the location of the detector within the section. Estimates for short time intervals display large random variation, and are definitely biased for time intervals during which sections are partially congested. Techniques based on matching cumulative flows at different locations avoid some of the problems with partially-congested sections, but require independent estimates of travel times for some vehicles (or alternatively, the number of vehicles in the section) and either frequent recalibration or sophisticated statistical techniques. These data are primarily useful for detecting order-of-magnitude changes in conditions, identifying time periods with congested flow, and (with a large enough sample) evaluating changes in average travel times resulting from freeway improvements.
- **Cost-Effectiveness:** Relatively high. In many cases, the marginal cost of collecting this type of data will be low because loops, counters/controllers, and communications systems are installed as part of ramp meter systems or real-time surveillance systems.



Cost-effectiveness of system extensions will vary, depending on communication system costs and potential use of data.

#### *Travel Time on Freeway Mainlines, Measured by Tach Car*

- **Requirements for Implementation:** Tach cars provide the ability to gather data on particular segments, but are not suitable for obtaining the massive quantities of data that can be provided by loops. Expansion of this means of measuring travel time requires additional vehicles and drivers.
- **Technical Feasibility:** Currently deployed.
- **Potential Value:** Travel time is one of the fundamental measures of system performance. The same basic data can also be reduced to estimate delay and average speeds on a section-by-section basis. Tach cars provide high quality data, but accuracy may suffer if samples are too small. Primarily useful for before-after comparisons for short segments of roadway.
- **Cost-Effectiveness:** Low. Useful for producing small quantities of very accurate data, but too expensive for wholesale implementation.

#### *Travel Time for Mainline Freeway Segments, Measured by Probe Vehicle*

- **Requirements for Implementation:** This is an experimental technique. Implementation will require installation of on-board transponders or electronic tags on a relatively large fleet of vehicles and installation of roadside hardware, communications systems, and data collection software. Where the vehicle fleet is composed of special purpose vehicles, such as emergency, commercial, or FSP vehicles, operational plans need to provide for adequate dispersion of vehicles across the highway network and for automatic exclusion of vehicles not in the traffic stream (e. g. on the shoulder for an enforcement or motorist assistance stop). Communications and data logging systems must be adapted to the asynchronous nature of the data. Further research may be required before decisions can be made as to suitability for implementation. There may also be a need to resolve issues of privacy and public acceptance prior to widespread deployment, at least for some versions of the technique.
- **Technical Feasibility:** Prototypical systems have been deployed on a trial basis
- **Potential Value:** Travel time is one of the fundamental measures of system performance. The same basic data can also be reduced to estimate delay and average speeds on a section-by-section basis. This technique could provide data quality similar to that of tach cars at a cost similar to that of loop detector systems; however, it does not provide volume counts, as do detector systems. Probe vehicles may

eventually become the primary source of travel time data for areawide traffic monitoring systems.

- **Cost-Effectiveness:** Potentially high, but further research and development are required.

*Travel Time for Mainline Freeway Segments, Measured by Identification/Reidentification Techniques*

- **Requirements for Implementation:** Experimental technique. Further research is required to verify accuracy and determine best approaches. Implementation would require sensors, sensor-data processing software, communications systems, and data collection software. This technique may involve privacy and public acceptance issues.
- **Technical Feasibility:** Not yet established.
- **Potential Value:** Travel time is one of the fundamental measures of system performance. Data accuracy will depend on the accuracy of vehicle matching. If vehicle matching is sufficiently accurate, this technique could provide data quality comparable to tach cars or probe vehicles. Cost is potentially lower than that of probe vehicles because on-board hardware is not required. This technique also has the advantage that any vehicle can be sampled. It could be used either for areawide monitoring or for special studies.
- **Cost-Effectiveness:** Unknown at this time.

*Travel Time for Freeway Ramps, Measured by Manual Queue Counts*

- **Requirements for Implementation:** Data collection crew, one or two people per ramp.
- **Technical Feasibility:** Currently used.
- **Potential Value:** Ramp delay data are necessary in order to correctly evaluate the performance of ramp metering systems. Currently, manual counts appear to be the only feasible source of ramp delay data. These are too expensive to be of much use for routine monitoring, but are useful for before-after studies of ramp metering investments.
- **Cost-Effectiveness:** Low. Data quality is good, provided samples are large enough to capture variations from day-to-day (minimum sample at least 5 days data recommended), but cost is very high.

### *Accident Rates by Freeway Section*

- **Requirements for Implementation:** For some applications, minor modifications to TASAS coding may be desirable.
- **Technical Feasibility:** Currently available through TASAS.
- **Potential Value:** Accident rates are a fundamental measure of traffic system performance. Accident rates for specific sections are also required for measurement of the performance of incident management systems. Quality of data in the TASAS database is considered to be very high relative to that in similar databases elsewhere; however, there is always a problem with underreporting of accidents, particularly those involving only property damage.
- **Cost-Effectiveness:** High; primary cost is the ongoing cost of TASAS.

### *Traffic Volumes for Specific Roadway Segments, Measured by Loop Detectors*

- **Requirements for Implementation:** Current loop detector systems provide partial coverage in urban areas; extensiveness varies considerably by region. More extensive coverage requires installation of loops, counters, and communications systems. Also, software to allow better integration of ramp meter and real-time surveillance system data with traffic census data may be desirable.
- **Technical Feasibility:** Currently deployed.
- **Potential Value:** Traffic volumes and derived measures such as VMT are fundamental measures of traffic system performance. In addition, they are required to interpret changes in other performance measures (for instance, increased delay could result from either increased traffic demand or from deterioration in system performance) and to calculate performance measures such as accident rates.
- **Cost-Effectiveness:** Relatively high. In many cases, the marginal cost of collecting this type of data will be low because loops, counters/controllers, and communications systems are installed as part of ramp meter systems or real-time surveillance systems. Cost-effectiveness of system extensions will vary, depending on communication system costs and potential use of data.

### *Traffic Information Accuracy*

- **Requirements for Implementation:** Implementation of an information quality control system requires 1) clear understanding of the types of traffic information being disseminated, their sources, and their means of dissemination; 2) personnel assigned to monitor information accuracy; and 3) a reporting system detailing the

types of information to be monitored, the frequency of monitoring, and the accuracy measures to be reported. Institutional changes may be required, since the person or persons responsible for information quality control will require the cooperation of a variety of units in the Caltrans organization. Also, some type of computerized logging system may be useful.

- **Technical Feasibility:** There do not appear to be serious technical feasibility issues; however, there will probably be institutional barriers. The most serious impediments to information quality monitoring are expected to be cost and the fact that additional personnel will probably be required.
- **Potential Value:** The accuracy of traffic information disseminated to the public (and other agencies) was identified as a major concern by attendees at the Caltrans Traffic Engineers Conference in March 1996. The ability to assess the accuracy of information as it is being disseminated is fundamental to any information quality control effort. The major benefit is expected to be better public relations.
- **Cost-Effectiveness:** Cost-effectiveness is difficult to predict until the scope of the monitoring effort is determined. It is probably fairly high, provided the requirement for additional personnel is not too much of a drawback.

#### *TMC Equipment Status (Fraction Functional)*

- **Requirements for Implementation:** Implementation requires complete inventories of TMC equipment, logging system and database software, personnel assigned to monitoring equipment status and logging equipment failures, and procedures for detecting and diagnosing equipment failures. In some cases, revisions to existing software to provide additional internal checks on data consistency may be useful.
- **Technical Feasibility:** Does not appear to pose any fundamental problems of technical feasibility.
- **Potential Value:** Equipment status may not be the most critical aspect of performance measurement, but it is useful in assessing the quality of data for other performance measures. From a management point of view, these data are also useful for assessing the impact of budget decisions, especially those affecting equipment maintenance.
- **Cost-Effectiveness:** Medium. Information does not reflect the performance of the system per se (although it will often be related to it); also, this performance measure may require additional staffing to monitor equipment status and prepare reports.

### *Incident Clearance Times*

- **Requirements for Implementation:** Implementation requires improved incident logging systems to facilitate searching/sorting of incident data files and software to calculate incident durations and produce reports. Improved reporting procedures for CHP may also be helpful, since there is a fairly high rate of non-reporting for incident clearance times. This is probably less a problem for major incidents where Caltrans traffic management teams are involved in the response.
- **Technical Feasibility:** There do not appear to be any fundamental problems of technical feasibility. Upgrading incident logging systems may require a fairly sophisticated software development effort, however.
- **Potential Value:** Incident duration is an important measure of the overall effectiveness of incident management systems. For routine incidents, however, this measure may be more dependent on the performance of the CHP and other emergency services providers than on the performance of the TMC. For major incidents where duration does depend more on TMC actions, circumstances may be nearly unique, so that duration is related more to the nature of the incident than to TMC performance. This measure may be most useful in routine monitoring of incident management intended to detect unexpected changes in performance.
- **Cost-Effectiveness:** Medium. Should be low cost, except possibly for initial software development effort to improve incident logging system. On the other hand, data may be of limited value in assessing TMC performance.

## APPENDIX C

### PROPOSED EVALUATION STUDY POLICY

In order to assess the effectiveness of investments and operational decisions related to the traffic management system, Caltrans will conduct evaluation studies for the traffic management actions listed below. As a general rule, the cost of performing evaluation studies shall be an integral part of the budget for the project being evaluated. Project schedules shall take into consideration the need for evaluation, and shall provide for adequate time to collect “before” data samples, where required; also, care shall be taken to ensure that sample sizes and data quality are comparable for “before” and “after” data. If necessary, special instrumentation may be installed to collect data.

#### **FUNCTION:** Ramp Metering

**ACTIONS:** Implementation of New System  
Extension of Existing System  
Major Change in Metering Operations  
    New Overall Control Strategy  
    Changes in Maximum/Minimum Metering Rates  
    Changes in Ramp Queue Constraints

#### **EVALUATION SPECIFICATIONS:**

##### **General:**

1. All actions have similar goals and require similar evaluations. The extent of the impact of the action is expected to vary with its scope.
2. Geographical scope of traffic data gathering: all metered ramps; all freeway segments in range of metering or normally experiencing congestion from bottlenecks downstream of metered ramps; all potential traffic diversion routes.
3. Proper gathering of before data may require that detectors, controllers, etc. be in place for a month or more prior to turn on of the system. This may require that system turn-on be delayed.
4. There will be a period of unstable performance immediately following implementation of a new system or major change in system operation as drivers adjust to the change. “After” data collection should begin a month to six weeks after implementation.
5. Evaluation studies should document costs of implementation and any known changes in operating costs that can be attributed to the new or modified ramp metering system.

**Issue:** Was delay reduced?

**Performance Measures:** Freeway travel time and delay before and after; ramp delays before (if any) and after; travel times on potential traffic diversion routes before and after.

**Data Collection and Analysis:** Travel time measurements before and after should be of comparable nature and scope. For instance, loop detector data should be compared with loop detector data, test car data with test car data, etc. Data collection should completely cover times of day for which meters are to be operational. Analysis of data should include means, standard deviations, distribution shapes (histograms or equivalent), and statistical tests of significance of differences in mean travel times. A minimum of twenty days' data should be collected both before and after.

**Issue:** Did traffic diversion or other changes in traffic patterns occur?

**Performance Measure:** Traffic volumes before and after for each freeway segment and on potential diversion routes.

**Data Collection and Analysis:** Traffic volume measurements before and after should be of comparable nature and scope. Data should be classified and compared by time of day for time intervals not to exceed 15 minutes. Data collection should completely cover times of day for which meters are to be operational. Analysis of data should include means, standard deviations, and statistical tests of significance of differences in mean traffic flow rates. A minimum of twenty days' data should be collected both before and after.

**Issue:** Were accident rates reduced?

**Performance Measure:** Accident rates before and after, classified by type of collision (rear end, sideswipe, etc.)

**Data Collection and Analysis:** Analysis should compare a minimum of one year's worth of data both before and after. A follow-up study comparing three years before and after may be desirable. Analysis should compare means and variances of accident rates and statistical tests of the significance of differences in mean rates.

**FUNCTION:** Incident Management

**ACTIONS:** New Incident Detection System  
Extended Incident Detection System  
New Incident Detection Algorithm

## **EVALUATION SPECIFICATIONS:**

### **General:**

1. Evaluation studies should involve direct comparison between the new or improved system and the existing system. Existing incident detection procedures (telephone calls, etc.) should be used to verify existence of incidents. Time of notification by conventional means should be recorded for purposes of comparison with the new or improved system.
2. Evaluation studies should document costs of implementation and any known changes in operating costs that can be attributed to the new or modified incident detection system.

**Issue:** Was detection time reduced?

**Performance Measure:** Time of detection with and without candidate system.

**Data Collection and Analysis:** Times of detection by existing and candidate systems should be recorded and compared. Analysis should include mean, variance, and statistical significance of reductions in incident detection times due to candidate system.

**Issue:** How accurate was incident detection?

**Performance Measures:** Detection rate and false alarm rate.

**Data Collection and Analysis:** Compare incident alarms with verified incidents to calculate detection rate and false alarm rate.

**FUNCTION:** Incident Management

**ACTIONS:** New Video Surveillance System  
Extended Video Surveillance System

## **EVALUATION SPECIFICATIONS:**

### **General:**

1. Evaluation studies involve direct comparison between the new or improved system and the existing system. Existing incident detection procedures (telephone calls, etc.) should be used to verify and assess incidents. Time of verification by conventional means should be recorded for purposes of comparison with the new or improved system.



2. Evaluation studies should document costs of implementation and any known changes in operating costs that can be attributed to the new or modified incident detection system.

**Issue:** Was incident verification time reduced?

**Performance Measure:** Time of verification with and without candidate system.

**Data Collection and Analysis:** Times of verification by existing and candidate systems should be recorded and compared. Analysis should include mean, variance, and statistical significance of reductions in incident verification times due to candidate system.

**Issue:** How accurate was incident verification?

**Performance Measures:** Rate of revised incident assessments.

**Data Collection and Analysis:** Record any cases in which information from field personnel results in a revised incident assessment. Calculate rate as fraction of all incidents for which initial verification via candidate system was revised.

**FUNCTION:** Incident Management

**ACTIONS:** Major Change in Incident Management Procedures

#### **EVALUATION SPECIFICATIONS:**

##### **General:**

1. Specific changes in incident management procedures will have specific objectives. Not all changes will involve all issues identified. Studies should focus on issues related to the objectives of the procedural change in question.
2. Evaluation studies should document known changes in operating costs resulting from changes in incident management procedures.

**Issue:** Were incident clearance times reduced?

**Performance Measure:** Incident clearance times before and after.

**Data Collection and Analysis:** Analysis should include mean and variance of clearance times before and after, and statistical significance of reductions in mean incident clearance times due to the candidate system.

**Issue:** Were secondary accident rates reduced?

**Performance Measures:** Rates of secondary accidents before and after.

**Data Collection and Analysis:** Review accident report narratives to identify secondary accidents before and after change. Calculate rate of secondary accidents per incident. Test null hypothesis that probability of secondary accidents is unchanged by new procedure.

**Issue:** Were traffic control and motorist information measures effective?

**Performance Measures:** Traffic volumes, speeds, travel times, etc. (as appropriate), before and after.

**Data Collection and Analysis:** Analysis of data should include means, standard deviations, and statistical tests of significance of differences in mean values of performance measures before and after institution of new procedures.

**FUNCTION:** Incident Management

**ACTIONS:** Acquisition of Major Items of Equipment to be Used in Incident Clearance

**EVALUATION SPECIFICATIONS:**

**General:**

Evaluation studies to document cost of acquisition and operation of new equipment.

**Issue:** Were incident clearance times reduced?

**Performance Measure:** Incident clearance times for appropriate types of incidents before and after.

**Data Collection and Analysis:** Analysis should include mean and variance of clearance times before and after, and statistical significance of reductions in mean incident clearance times due to new equipment.

**FUNCTION:** Motorist Assistance

**ACTION:** New or extended freeway service patrol (FSP)

## EVALUATION SPECIFICATIONS

### General:

1. The prototypical FSP evaluation study is Skabardonis et al (PATH Research Report UCB-ITS-PRR-95-5, 1995). Some of the methodology of this study is too elaborate for routine application. Its results indicate that FSP service is unlikely to result in statistically-significant reductions in overall freeway delay. Evaluation studies should concentrate on assistance rates, reduction in incident clearance time, and public satisfaction with service.
2. Evaluation studies should document costs of implementation and any known changes in operating costs that can be attributed to the new or extended FSP

**Issue:** How does assistance rate compare with other FSPs?

**Performance Measure:** Number of assisted incidents per month per vehicle-hour of FSP service

**Data Collection and Analysis:** Analysis should involve comparisons with assistance rates of other FSP services. Comparisons should include means and standard deviations of monthly assistance rates, and statistical tests of significance of differences in mean rates.

**Issue:** Were clearance times for assisted incidents reduced?

**Performance Measure:** Average clearance time for assisted incidents before and after introduction of FSP

**Data Collection and Analysis:** Analysis should include mean and variance of clearance times before and after, and statistical significance of reductions in mean incident clearance times due to FSP. Note: this is the methodology of the Skabardonis study. See Skabardonis et al for a method for estimating delay reduction based on reduction in clearance time for assisted incidents. There may be data comparability problems with this methodology. Introduction of FSPs tends to increase the number of incidents that are assisted. Since it is impossible to determine which unassisted incidents in the “before” sample would have received assistance from the FSP, it is not possible to determine changes in clearance times for incidents which were unassisted before but would have been had there been an FSP. Comparison of average clearance times for assisted incidents before and after may not be valid because it ignores changes in clearance times for these incidents.

**Issue:** How satisfied is the public with the FSP service?

**Performance Measure:** Public satisfaction as determined from opinion surveys.

**Data Collection and Analysis:** Data should be collected by means of surveys of motorists who are assisted by the FSP and of other motorists using the FSP beat in question. Where possible, results should be compared with those of other FSP services.

**FUNCTION:** Data collection, management, and dissemination

**ACTION:** New or improved data access system

## **EVALUATION SPECIFICATIONS**

### **General:**

1. Evaluation should determine extent to which the new or improved data access system meets the needs of external data users.
2. Evaluation studies should document costs of implementation and any known changes in operating costs that can be attributed to the new or improved data access system.

**Issue:** Are data access system users satisfied with the new or improved system?

**Performance Measure:** No quantitative measure; qualitative assessment of system effectiveness.

**Data Collection and Analysis:** Data collection may be through questionnaires administered to external data users or informal written assessments solicited from them. Goal of data collection and analysis is to determine whether the new or improved system meets the needs of its users, how it can be improved, etc.

## APPENDIX D

### PROPOSED PERFORMANCE MONITORING SYSTEM

#### Introduction

The main goal of performance monitoring is to identify significant changes in the performance of the traffic system or the traffic management system that require a response, especially unexpected ones. The basic strategy is to extract as much information as possible out of the available traffic data. Since the focus is on detecting changes in performance, absolute accuracy of the data is of less importance than comparability over time.

Traffic performance monitoring is intended to support the total effort of Caltrans (and other agencies involved in the planning, design, and operation of the transportation system) as it relates to the quality of traffic service. In particular, performance monitoring should accomplish the following:

- Provide traffic operations units with feedback concerning the effectiveness of current operational strategies and information about possible needs for operational improvements.
- Provide planning units (both inside and outside Caltrans) with information about needs for improved traffic service (which may require expansion of physical facilities, operational improvements, or some combination of the two) and feedback on the results of past improvements.
- Provide Caltrans management with information about trends in the quality of traffic service and the overall performance of Caltrans as it relates to traffic service.
- Provide elected officials and the public with information about trends in the quality of traffic service and what Caltrans is doing to solve traffic problems and improve traffic flow.

A major issue in the design of performance monitoring systems is identification of potential users of monitoring reports and determination of their exact needs in terms of types of information, frequency of reporting, and report formats. The traffic monitoring system proposed here is primarily intended to make use of existing information sources. Future development of the traffic information system, however, should be guided by the needs of all potential users. This will require extensive discussions, which should involve Caltrans planning and traffic operations units at both the district and headquarters levels, as well as outside agencies such as metropolitan planning organizations (MPOs), other regional planning agencies, and local governments.

To reduce costs, monitoring reports should be produced automatically where possible. Given the expense and delay involved in developing specialized software, however, a mixture of automatic and semi-automatic report preparation will probably be most appropriate, at least initially. For the most part, data aggregation and display will be straightforward. Most aggregation and graphics tasks can be performed either by spread sheets or a combination of simple custom software and spread sheet functions.

Performance indicators that can be incorporated immediately (or nearly so) include:

- Loop detector data and measures derived from them, such as flow rates, estimated average speeds or travel times, and delays.
- Accident rates.

Performance indicators that may require further development of data collection systems include:

- Rates of incidents other than reported accidents
- Incident clearance times
- Equipment status
- Information accuracy

Current-generation data management and display systems such as the software package developed by Caltrans District 12 and the National Electronic Technologies (NET) Corporation have the capability of producing incident and equipment status logs in database form. Some manual effort may be required for tasks such as extracting incident clearance times from these databases.

### **Geographical Aggregation Levels**

Freeway networks may be structured to establish the following levels of geographical aggregation for data:

*Section.* The basic freeway section is directional and is defined by entrances, exits, or other significant features such as lane drops, major changes in grade, etc. In general, sections should not extend beyond entrances or exits (that is, every entrance and exit is a section boundary) and boundaries of sections for opposing directions need not coincide. Detector data, accident data, and equipment status information can be related to specific locations identified by post mile and can hence be assigned to individual sections. In

some cases, incident data (other than accident data) is available by post mile; otherwise it can be recorded at the section level.

*Segment.* Freeway segments consist of one or more sections (usually 5 to 10 sections) and are bounded by freeway-to-freeway interchanges or major bottlenecks. Like sections, segments are directional. Boundaries of segments in opposite directions need not coincide, although in most cases they will.

*Sector.* Network sectors are connected portions of the freeway network consisting of several segments. Urbanized counties will normally involve several sectors, although this depends on the size of the county and the complexity of the network.

*County.* An entire county or the portion of a county in a particular Caltrans district.

*Caltrans District.* An entire Caltrans district. District boundaries do not always coincide with county lines.

It may not be useful to provide monitoring reports for all levels of geographical aggregation. As a general rule, the *segment* (as defined above) should be the basic level for monitoring reports. Use of *sections* will produce too much detail to be readily comprehended; also, detector data may not be available for every section. Aggregation of data beyond the segment level may lead to problems of comparability if data collection systems are expanded to include more segments. This problem relates primarily to detector data, since other performance indicators do not depend on a fixed infrastructure. This problem can also exist at the segment level, but it is less likely to create confusion, since segments with incomplete data collection systems will probably be omitted anyway. Performance indicators that do not depend on detector data, such as accident rates, incident rates, incident clearance times, and equipment status, may be aggregated to any level that seems reasonable. At a minimum, these measures should be aggregated to the district level, since most decision making related to them will affect the entire district.

## **Reporting Periods**

Reporting periods, like geographical levels for monitoring reports, need to be chosen so as to provide sufficient detail without overwhelming the reader with information. Also, temporal aggregation of data needs to be over a long enough period of time to attenuate random variations.

Raw data are available for very short time intervals. In the case of detector data, reporting intervals are often in the range of 30 seconds to 1 minute. Accidents, incidents, and equipment status changes occur randomly in time, although they may not be reported immediately. In the case of reported accidents, for instance, two or three months will normally elapse before the data are posted to the Traffic Accident Surveillance and Analysis System (TASAS) database.

The minimum reporting interval should be one month, since anything less than this will involve too much random variation. Monthly reports should be aggregated to produce quarterly and annual reports.

## **Report Formats**

Monthly reports should provide the following information for each *segment* (see definition in section entitled Geographical Aggregation Levels) for which data are available:

- *Vehicle-miles of travel*: Average daily travel (for the entire 24-hour period); daily average peak hour travel (based on the highest hour each day -- not necessarily the same hour every day); and daily average peak 15-minute travel (based on the highest 15-minute period each day). Data for weekdays and weekends/holidays should be presented separately. Trend charts including the most recent 24 months or all available data (whichever is less) should be prepared for each category of data.
- *Average speed or estimated average travel time per vehicle*. Estimated speed or average travel time per vehicle aggregated over the entire month and the fraction of time that speeds are below (or travel times are above) specified thresholds. Data for weekdays and weekends/holidays should be presented separately. Trend charts including the most recent 24 months or all available data (whichever is less) should be prepared for each category of data.
- *Total delays* in vehicle-hours per section per five-minute interval (daily plots).
- *Accident rates*. All accidents and accidents classified according to fatal, injury, and property damage only. Trend charts including the most recent 24 months or all available data (whichever is less) should be prepared for each category of accident.
- *Equipment status* (if available). Equipment status by type of equipment. Trend charts including the most recent 24 months or all available data (whichever is less) should be prepared for each type of equipment and equipment status category.
- *Incident rates* (if available). Incident rates classified by major incident category. Trend charts including the most recent 24 months or all available data (whichever is less) should be prepared for each category of incident.

Accident rates, incident rates, and equipment status data should be aggregated up to the district level, with trend charts prepared for the most recent 24 months or all available data (whichever is less). In addition, the following information should be reported at the district level:



- *Incident clearance times* (if available). Average incident clearance times for all incidents and for major incidents (that is, those for which traffic management teams were dispatched) classified by category of incident. Trend charts including the most recent 24 months or all available data (whichever is less) should be prepared for each category of incident.
- *Information accuracy* (if available). Fraction of correct (or incorrect) messages by message category. Trend charts including the most recent 24 months or all available data (whichever is less) should be prepared for each message category.

Quarterly report formats should be similar to those for monthly reports, except that monthly data should be aggregated for the entire quarter and trend charts should involve the most recent 24 quarters or all available data (whichever is less). Annual report formats should also be similar to those for monthly reports, except that data should be aggregated for the entire year. Trend charts for annual data should include the most recent 10 years or all available data. Also, the 24-month quarterly trend charts should be repeated in the annual reports.

All reports should include a narrative analyzing any significant or unexpected changes in performance. An executive summary should be prepared, highlighting the most significant findings.

### **Report Distribution**

Monitoring reports should be distributed to Caltrans units and other agencies that need to be aware of long-term changes in traffic conditions and traffic system performance. In general, this includes units involved in operations, maintenance, planning, project development, and public information. The internal organization of Caltrans districts varies a great deal, so that the units preparing and receiving reports will have different titles in different divisions. Reports will normally be prepared by units reporting to a Deputy District Director of Operations or Operations and Maintenance. The unit directly responsible may be the TMC itself or may be entitled Traffic Studies, Traffic Systems, Traffic Management, etc. Actual report preparation may also be performed by a consultant under contract to this unit. Quarterly and annual reports should be routed through the District Division Chief responsible for traffic functions to the District Director and to the Caltrans Headquarters Divisions of Materials, Research and New Technology and Traffic Operations. In addition, reports should be distributed to the local metropolitan planning organization (MPO) and to other local agencies that request them.

These recommendations are tentative: exact distribution lists and routing for reports should be determined through discussions within Caltrans and between Caltrans and other interested agencies.

## **Additional Analysis Capabilities**

Although the minimum reporting interval is one month and the basic geographical unit for performance monitoring reports is the freeway segment, data management and display software should allow data to be accessed at a more detailed level for purposes of analysis. These analyses will be particularly important when performance monitoring reveals an unexpected problem that needs to be explained. All data included in segment-level reports should also be accessible at the section level. Specifically, software should be capable of producing the following displays:

- Traffic volumes, average speeds, travel times, and total delays for individual sections, for five and fifteen minute time intervals.
- Fraction of total time above or below travel time or speed thresholds for individual sections.
- Space-time contour displays of average flows, speeds, and travel times for specific days.
- Space-time contours (by time of day and section) of fraction of time above or below travel time or speed thresholds, for extended periods of time such as a month or a quarter.
- Time series of flows and speeds or travel times for individual detector stations. Software should have the capability of producing time series graphs over varying periods of time, so that data can be graphed for all day, for a peak period, or for some other specific period of time.
- Incident and accident rates by section.