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Authors

Banks, James H.
Kelly, Gregory

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INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

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of Effectiveness, and Proposed Action Priorities**

James H. Banks, Gregory Kelly
San Diego State University

**California PATH Research Report
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TRAFFIC MANAGEMENT SYSTEMS PERFORMANCE MEASUREMENT

WORKING PAPER #1

STUDY DIRECTION AND SCOPE, PROPOSED MEASURES OF EFFECTIVENESS, AND PROPOSED ACTION PRIORITIES

by

James H. Banks
Gregory Kelly

Department of Civil and Environmental Engineering
San Diego State University
San Diego, CA 92182-1324

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ABSTRACT

This report documents research to 1) analyze performance measurement requirements associated with for California Department of Transportation (Caltrans) Transportation Management Centers (TMCs), 2) identify and assess the feasibility of data collection and management activities required to support TMC performance measurement, and 3) recommend specific actions by Caltrans and PATH that will facilitate performance measurement. Performance measurement will be most effective in the evaluation of new, expanded, or improved TMC functions and in monitoring the traffic system to detect changes in performance. It is less likely to be effective in the evaluation of existing TMC functions or in comparisons between different TMCs. Major TMC functions include ramp metering, incident management, traveler information, motorist assistance, and data collection, management, and dissemination. Major measures of effectiveness related to these 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. 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 actual 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, development of an equipment status logging system, development of improved incident logging systems, 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 the first year of a research project focusing on performance measurement for California Department of Transportation (Caltrans) Transportation Management Centers (TMCs). Project objectives are 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, and 3) recommend specific actions by Caltrans and PATH that will facilitate performance measurement.

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*. It may apply to the whole highway system (or some portion of it); a TMC; or specific traffic management activities. It also includes both the *description* and *evaluation* of traffic flow and traffic system management activities.

A major challenge in measuring the performance of TMCs is separating the effects of TMC actions from those of external circumstances. Circumstances not under the direct control of TMCs that affect traffic system performance include travel demand patterns, highway system configurations, driver characteristics, and the policies and procedures of other agencies such as emergency services providers. Because of the need to account for the effects of external circumstances, performance measurement will be most effective in the evaluation of new, expanded, or improved TMC functions and in monitoring of the traffic system to detect changes in performance requiring corrective action. Performance measurement is less likely to be effective in providing a basis for evaluating or justifying continued operation of existing TMCs or comparing the performance of different TMCs. Evaluation of new, expanded, or improved TMC functions can best be accomplished by means of carefully-designed before-and-after studies. Early warning of changes requiring corrective action can best be accomplished through continuous, systematic monitoring of selected performance indicators.

Major TMC functions include ramp metering, incident management, traveler information, motorist assistance, and data collection, management, and dissemination. Major measures of effectiveness related to these 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, and it will be

expensive to extend it. 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.

Actions to improve performance measurement that can be undertaken immediately include development of a policy for evaluation of investments in TMC functionality, research to compare loop-detector-based travel time estimates with actual travel times, development of a quality control system for traffic information disseminated to the public, development of a monitoring system plan for traffic system performance, research concerning the feasibility of relating incident and accident data, development of an equipment status logging system, and development of improved incident logging systems. Possible future actions include further research on non-loop-based travel time measures, extension of loop detector coverage, and development of data reduction and display software for a performance monitoring system.

TABLE OF CONTENTS

	<u>Page</u>
TABLES.....	iii
ILLUSTRATIONS.....	iv
INTRODUCTION.....	1
PROJECT ACTIVITIES.....	1
LITERATURE SURVEY.....	3
PROJECT DIRECTION AND SCOPE.....	4
Definition.....	4
Performance Versus the Effect of External Circumstances.....	5
Feasibility of Different Performance Measurement Applications.....	6
Project Direction.....	7
MEASURES OF EFFECTIVENESS.....	7
Objectives.....	7
Measures of Effectiveness.....	9
Measurement Techniques and Issues.....	11
Travel Time and Related Measures.....	11
Ramp Delay.....	15
Traffic Volumes.....	15
Accident Rates.....	15
Traffic Information Accuracy.....	15

Incident Clearance Times.....	15
	<u>Page</u>
Equipment Status.....	16
Cost-Effectiveness of MOEs.....	16
ACTION PRIORITIES	17
Possible Immediate Actions	17
Possible Future Actions.....	20
REFERENCES.....	21
APPENDIX -- COST-EFFECTIVENESS ANALYSIS SUMMARIES FOR MAJOR MEASURES OF EFFECTIVENESS AND MEASUREMENT TECHNIQUES	25

TABLES

	<u>Page</u>
Table 1. Relationship Between Objectives and Measures of Effectiveness.....	12
Table 2. Cost-Effectiveness of MOEs and Measurement Techniques.....	16

ILLUSTRATIONS

Page

Figure 1. Determination of Travel Time from Cumulative Vehicles Counts	14
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INTRODUCTION

This report documents the first year of a research project entitled “Traffic Management Systems Performance Measurement.” This project, which is sponsored by the California Partners for Advanced Transit and Highways (PATH) Program, focuses on performance measurement for California Department of Transportation (Caltrans) Transportation Management Centers (TMCs). The project is primarily concerned with performance measurement issues associated with the urban freeway system, and does not explicitly consider non-Caltrans efforts such as local TMCs, although some of its findings may also be applicable to them.

Project objectives are 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, and 3) recommend specific actions by Caltrans and PATH that will facilitate performance measurement.

The first year of the project involved several research tasks. These included discussions with PATH and Caltrans personnel that were intended to refine the objectives and priorities of the project, a literature survey, an analysis of proposed measures of effectiveness (MOEs) for traffic system and TMC performance, and the identification and prioritization of specific actions intended to improve performance measurement. A second project phase will include preparation of data system improvement plans for TMCs in San Diego and Orange County (Caltrans Districts 11 and 12). These plans are intended to improve the ability of these TMCs to support performance measurement.

This report documents the scope and priorities of the project, a set of proposed measures of effectiveness for TMC functions, and a tentative list of priorities for actions designed to improve TMC performance measurement.

PROJECT ACTIVITIES

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 January 25, 1996 to review the scope of the project. Based on this meeting and subsequent discussions, it was decided to seek input from Caltrans traffic management personnel at a session of the 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.

A literature survey was also conducted. The initial survey concentrated on past work on TMCs that had been conducted by PATH, references cited in the PATH reports, and ITS America documents related to the development of the national ITS system architecture. These references provided background for understanding the scope of existing and future TMC activities, as well as a number of specific issues related to TMC organization and functioning. Additional literature was reviewed later. These additional references provided insight into some of the underlying concepts involved in performance measurement and information about specific measures of effectiveness and measurement techniques.

Objectives of specific TMC functions were identified based on the literature survey and the discussions with Caltrans and PATH representatives. Based on these objectives, potential MOEs were proposed for the traffic system as a whole, the TMCs, and specific TMC functions. The cost-effectiveness of these potential MOEs was then analyzed. A detailed analysis sheet was prepared for each proposed MOE evaluating (in general terms) its

- Potential accuracy
- Ability to capture variations in performance
- Potential measurement frequency
- Set-up cost for data-collection and reduction systems
- Ongoing cost of data collection
- Staffing requirements
- Hardware requirements
- Software development requirements
- Compatibility with existing data systems and
- Institutional issues expected to be involved.

Based on these detailed analysis sheets, summary analyses were prepared for what were considered to be the most important candidate MOEs. Each summary listed

- Requirements for implementation of the MOE
- A qualitative assessment of its technical feasibility
- An assessment of its potential value as a performance measure, and
- A qualitative evaluation of its cost-effectiveness.

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 which 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 and feasibility. The action priorities are presented in a subsequent section of this report. The MOE Analysis Summaries are included as an appendix.

LITERATURE SURVEY

The literature survey focused on the underlying concepts involved in performance measurement, previous work on performance measurement related to traffic management systems, the scope of existing and future TMC activities, specific issues related to TMC organization and functioning, and the details of specific measures of effectiveness and measurement techniques.

Although the term *performance measurement* has only rarely been used to describe efforts to evaluate the performance of traffic management systems (1,2), there is an extensive literature describing the evaluation of traffic management and data collection techniques (3-28). This literature raises a number of issues related to feasibility and accuracy of various measurement techniques and provides a starting point for defining measures of effectiveness for TMC performance measurement.

Concepts similar to performance measurement are occasionally encountered in the literature of fields other than traffic engineering. Wilson and Pearson (29), for example, describe a technique known as *performance-based assessment*, which is used in total quality management studies. Although this is a somewhat different concept from performance measurement as applied to the traffic field, the discussion in Wilson and

Pearson provides considerable insight into some of the underlying issues and concepts involved in performance measurement.

Past work sponsored by PATH provides information about the scope of existing and future TMC activities and specific issues related to TMC organization and functioning. Lo, Hall and Windover (30) conducted site visits of all Caltrans and three city TMCs to assess existing capabilities, including TMC functions: coordination between TMCs and coordination of TMCs with other agencies; and facilities, communication media, and software and databases.

Past work sponsored by PATH related to TMC organization and functioning includes a series of reports on the concept of Computer Integrated Transportation. This refers to a network of public and private transportation organizations, each with unique responsibilities, working toward a common goal of facilitating travel across all modes of transportation. In-depth studies were performed for Arterial and Highway TMCs by Hall, Lo and Minge (31), for Emergency Operations by Lo and Rybinski (32), and for Commercial Vehicle Operations by Hall and Chatterjee (33). Based on this work, Hall, Lo and Minge (34) concluded that four factors have profound implications for ITS implementation and research: time-frame, linking information to actions, broadcast orientation, and embracing of new technologies.

Other literature related to TMC organizational issues includes a survey of six metropolitan areas by Booz-Allen and Hamilton (35) to determine institutional barriers to coordinated traffic management and recommend solutions to these; and Carvell et al (36), which describes successful interagency communication and coordination in a traffic signal control project in northern Dallas County, Texas.

Another major source of information about possible future TMC organization and functioning is a set of documents related to the development of the National ITS (formerly IVHS) System Architecture. A preliminary document by IVHS America (37) presents the Architecture Development Program in terms of its organizational structure and six groups of 28 (currently 29) user services. Mitretek Systems (38) provides information on the Intelligent Transportation Infrastructure (ITI) for transportation managers in metropolitan areas.

PROJECT DIRECTION AND SCOPE

Among the more important issues that had to be addressed in the first year of the project were its direction and scope. Several rather subtle issues were involved. These included the definition of the term *performance measurement*, the feasibility of various performance measurement objectives, the differing perspectives of Caltrans, PATH, and the project team on performance measurement priorities, and the project's specific direction in light of these differing perspectives.

Definition

Although there have been past efforts to measure the performance of traffic management systems (1,2), they do not involve a formal definition of the term *performance measurement*. A similar term, *performance-based assessment*, has been used in the context of total quality management (TQM) studies. In this usage, it implies an assessment that goes beyond evaluating compliance with predetermined requirements or overall system effectiveness to consider “targeting” -- that is, the appropriateness of the activity itself (29).

This definition seems to go beyond what is meant in the traffic context, where the emphasis is on an ongoing process of gathering data about the system. For purposes of this study, the following definition will be adopted: *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*. In this sense, it is possible to measure the performance of the whole highway system (or some portion of it); a TMC; or specific traffic management activities such as ramp metering, incident management, or traffic information dissemination.

The exact meaning of performance measurement may vary depending on what is being measured. In ordinary usage, *performance* has both a descriptive and an evaluative sense; that is, it may refer either to the way something functions or to the extent to which its functioning meets expectations. Performance measurement for the traffic system as a whole usually means *describing* particular aspects of its functioning; performance measurement for a TMC or a TMC function usually means *evaluating* the extent to which it meets objectives related to improvement of system performance.

Performance Versus the Effect of External Circumstances

In evaluating a TMC or TMC function, it is necessary to distinguish between changes in traffic system performance that are due to TMC activity and those due to various external circumstances, such as travel demand patterns, highway system configurations, and driver characteristics. In addition, the operational effectiveness of existing traffic management systems will be limited by their design features, including their functional capabilities and the location of equipment such as ramp meters, CMSs, and surveillance systems. Only after these limitations are understood can there be an assessment of performance.

In the case of ramp metering systems, for example, it is reasonable to assume that potential metering effectiveness (in terms of minimizing delay) is limited by the interplay of demand patterns and ramp configurations. Within these constraints, potential effectiveness is further limited by such system design features as the selection of ramps to

meter, the basic metering discipline (number of lanes past the meter, number of vehicles per green, and so forth), and the degree to which the system is traffic responsive.

Where the effects of such features are well-understood, it may be possible to evaluate system performance against its theoretical limits. More commonly, there is a lack of universally-accepted theory outlining optimum control strategies, the theoretical limits of operational effectiveness, and the ways external factors affect these. In this case, it may be possible to evaluate *changes* in operating strategy within a given system but not the effectiveness of the system itself or the relative performance of different systems.

Operational changes within a system can be evaluated if external circumstances and system design features remain more or less fixed before and after the change; but in attempting to evaluate the performance of the system itself, there is no way to separate the effects of the operating strategy from those of external circumstances and system design features.

For example, if different ramp metering strategies are used in Los Angeles and San Diego, it is not valid to compare these by merely comparing delay per vehicle on metered freeways in the two cities. Such a comparison would be misleading because the two metering strategies are applied in entirely different settings, and any differences in delay are as apt to be due to differences in demand or ramp configurations as to differences in strategy.

Feasibility of Different Performance Measurement Applications

Performance measurement may be applied to Caltrans TMCs in a number of different ways. These include:

- Systematic, continuous monitoring of the traffic system to provide early warning of changes requiring corrective action.
- Evaluation of new, expanded or improved TMC functions.
- Benefit-cost analysis intended to evaluate (or justify) continued operation of existing TMCs.
- Comparisons of the performance of different TMCs.

In initial discussions, study participants expressed rather different priorities regarding these potential applications. PATH representatives focused on benefit-cost analysis of specific TMC functions, Caltrans managerial staff expressed interest in justification of TMC budgets and comparison of the performance of different regional TMCs, and the

Project Director focused on evaluating of new TMC functions and routine monitoring of the freeway system. Decisions about the specific directions to be pursued in the project were ultimately based an assessment of the feasibility and potential value of these various applications.

The feasibility of specific TMC performance measurement applications is primarily limited by the problem of differentiating between the effects of TMC activities and external circumstances. Feasible applications include continuous monitoring of traffic system performance to provide early warning of changes and evaluation of new TMC functions or changes in TMC operations. Monitoring traffic system performance is primarily descriptive and thus avoids the need to control for external circumstances. Evaluation of new TMC functions or changes TMC operations does involve controlling for the influence of external circumstances, but in many cases this can be accomplished by means of carefully-designed before-and-after studies. On the other hand, it is not really possible to compare the operational effectiveness of different TMCs, nor to evaluate the success of specific past TMC investments for which no “before” data exists.

Consequently, it was concluded that two basic types of performance measurement can be pursued. 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.

Project Direction

Based on this analysis of the nature and objectives of performance measurement, it was decided that the project should address both routine system monitoring and evaluation of specific traffic management actions. In the case of the latter, one of the project’s objectives is to recommend a policy for the conduct of evaluation studies. This recommended policy will spell out, for specified actions, the types and amounts of data that need to be collected and will identify the data collection facilities required to support such studies. In the case of the former, the project will develop a set of options for setting up a performance monitoring system, recognizing that Caltrans management will need to make decisions about the scope of the effort as well as some of its details.

MEASURES OF EFFECTIVENESS

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 the 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.

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. The exact list of TMC functions varies by Caltrans District. In addition, in some cases “TMC functions” may be performed by related traffic management units. In general, however, the TMCs perform the following functions:

- *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.

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 to *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*.

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, carbon monoxide, etc. 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.
- *Equipment Status.* Equipment status is the fraction of equipment functioning properly, as opposed to that either not functioning or producing erroneous data.

Table 1 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
- Traffic information accuracy
- Incident clearance times, and
- Equipment status

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.

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.

Table 1. 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										x		x
External Circumstance												
Travel Demand			x									
TMC Workload							x	x				

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.

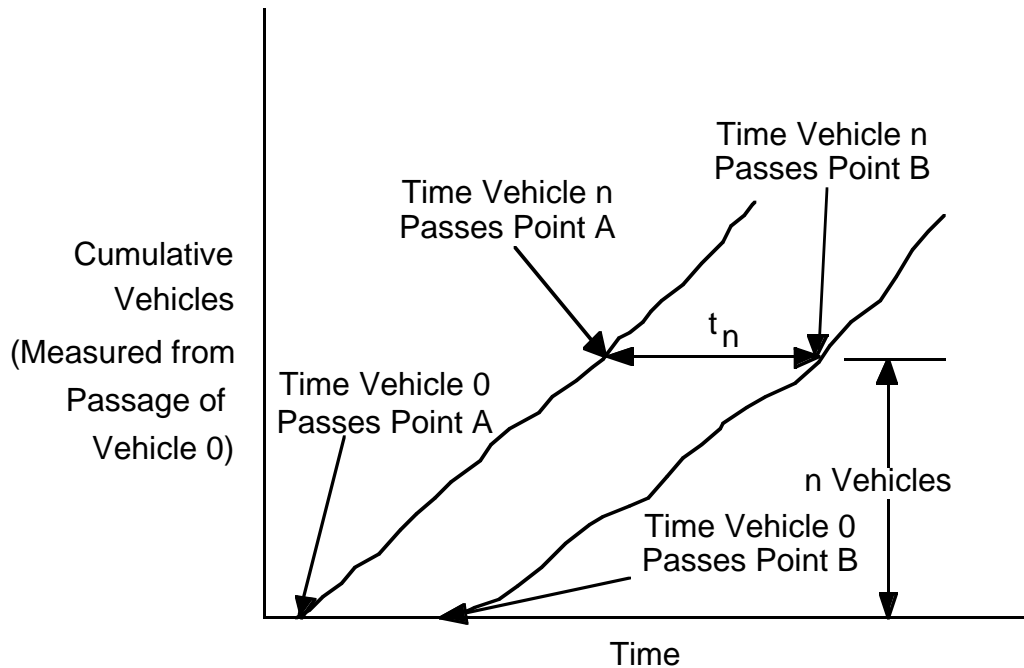
The second technique attempts to identify the time difference between cumulative flow functions at two different locations. If the time that a single vehicle passes both points can be identified, counts are perfectly accurate, and there is no traffic entering or leaving the traffic stream between the 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.

Different versions of this technique have been used in past performance measurement studies (1) and, more recently, in experimental work related to incident detection (26; also ongoing work by Karl Petty at U. C. Berkeley). 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. The extensiveness of these systems varies significantly among the urbanized Caltrans Districts.

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



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.

Ramp 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.

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.

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.

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.

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.

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.

Cost-Effectiveness of MOEs

Summaries of cost-effectiveness analyses for the major MOEs and measurement techniques are presented in an appendix. Table 2 presents a summary of the overall results of this analysis.

Table 2. 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				

ACTION PRIORITIES

A major project goal is to identify specific actions that can be undertaken by Caltrans or PATH to improve traffic management systems performance measurement. A tentative list of actions has been identified. These actions have also been prioritized, based on the relevance of the action to Caltrans' goals and performance measurement priorities, ease of implementation, resource requirements, and the extent to which other actions need to be completed prior to implementation. This list is divided into actions that can be undertaken immediately and possible future actions.

Possible Immediate Actions

- . *Develop a policy for evaluation 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. It is expected that a recommended policy will be developed as part of this project, but Caltrans will need to refine the policy and make management decisions about whether and how to implement it.
- . *Conduct research to compare loop-detector-based travel time estimates with actual travel times.* Caltrans has a major investment in the existing loop-detector system, but questions have been raised about its suitability for estimating travel times. Specific questions relate to the accuracy of speed estimates based on single-loop detectors and possible biases resulting from generalization of point data to represent travel time across an extended section. Before embarking on either major expansion of the loop detector system or implementation of an alternative system, these questions should be settled. Proposed research involves comparisons of travel time estimates derived from loop detector data with actual travel times as determined by test car runs. Comparisons should be carried out for various locations and traffic conditions (congested, partially congested, uncongested, etc.) Also, because there are reported variations in the accuracy of counts depending on the geographical area, research should be conducted in more than one District. Recent PATH research has compared measured travel times with detector-based travel time estimates. These projects have been concerned with the possible use of cumulative-flow methods to estimate travel times for incident detection. These efforts are concerned with the accuracy of travel time estimates over very short time intervals and may require very frequent polling of traffic counters. The research suggested here would differ from

this work in that it would involve longer time intervals for averaging travel times, larger sample sizes of test car data, and evaluation of several techniques for estimating travel times from spot speed data, including generalization of spot speeds (both measured speeds from double loops and estimates speeds from single loops) and various versions of the cumulative-flow method. Depending on the scope of the project and the extent to which Caltrans can provide use of resources such as test cars, it should be possible to accomplish this research for \$50,000 - \$150,000.

Develop Quality Control System for Traffic Information Disseminated to the Public. Information accuracy has been identified as a major concern by Caltrans personnel. Currently, there is no organized way of monitoring the accuracy of information disseminated to the public. Information quality-control systems are expected to vary from District to District depending on the types of information disseminated. Development of a quality-control system 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. It is expected that prototypical information quality control systems will be developed by this project as a part of data system improvement plans to be prepared for Districts 11 and 12. These plans will need to be adapted to conditions in other districts; in addition, Caltrans management decisions will be necessary to implement them, and it may be necessary to provide additional staffing to carry them out.

Develop a monitoring system plan for traffic system performance. Data currently collected by TMCs forms an important resource that could be used to give early warning of unexpected changes in the performance of the traffic system. 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, incident rates (other than accident rates), and the like. 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. A discussion of possible options for routine performance monitoring will be provided as a part of this project, but Caltrans management will need to make decisions about the scope of the effort. Also, implementation of this plan may require additional staffing.

- . *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. Expected cost of this research is \$30,000 to \$60,000.
- . *Develop an equipment status logging system.* Equipment status logs are required to assess the ability of TMCs to keep equipment operating. In addition, information on equipment status is important in assessing the accuracy of other information produced by TMCs. This action involves developing software to record TMC equipment status on a continuous basis, and to produce reports summarizing this information on a periodic basis. It is also possible to keep logs by hand, but computerized logs should be more efficient in the long run. Minimum information needed is a record of the time and date of every change in status, for every piece of equipment in the TMC inventory. A classification system for equipment status, such as operational, operational with errors or problems, or non-operational, will also have to be developed. This is expected to be a relatively straightforward software development project. Implementation of a computerized equipment logging and reporting system will also require management decisions by Caltrans, and may involve a need for additional staffing.
- . *Develop an improved incident logging system.* Several proposed measures of effectiveness are dependent on an improved incident logging system. These include incident durations and incident rates by type of incident and freeway section. Any modifications of existing software should reduce operator workload if possible, and in any case not increase it. The proposed action is to develop improved incident logging software to provide for the following: 1) Ability to sort incidents by location; 2)

Ability to sort incidents by type, based on a standardized classification system; 3) Automatic calculation of incident duration; 4) Reduced operator workload; 5) Statewide consistency in incident log format; and 6) Easy access to non-sensitive portions of the historical incident database. If feasible, cross-referencing to entries in the TASAS accident record database is also desirable. It is expected that this project will require a substantial software development effort. Improvements envisioned here will probably require some type of graphical user interface for ease in entering information by the operators. In order to facilitate sorting, locations will probably need to be described in terms of predetermined freeway sections and incident types in terms of a standard classification system. Management decisions will be required to determine the exact format of the incident log and the details of classification systems for incident types and locations.

Possible Future Actions

- . *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 verify their accuracy and to work out the details of how they might be implemented. Ongoing research should be continued, but major expenditures on these techniques should be postponed pending the results of research comparing measured travel times with those estimated from loop detector data.
- . *Extend loop detector coverage.* If a performance monitoring system is instituted, expansion of the loop-detector-based traffic counting system may be needed to provide section-by-section travel time estimates on a geographically-comprehensive basis. In addition, expansion of detector coverage could result in more comprehensive volume counts and better VMT estimates. 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 system is expected to take place as ramp meter and real-time surveillance systems are expanded. Major expansion of the loop detector system *for the sole purpose of monitoring traffic system performance* should be postponed pending results of research comparing actual travel times with those estimated from loop-detector data and development of a performance monitoring plan. The extensiveness of the existing system varies considerably from District to District. Expansion to provide comprehensive coverage for all California metropolitan areas would probably cost in the tens of millions of dollars.
- . *Develop data reduction and display software for the performance monitoring system.* It is expected that any system for monitoring the overall performance of the traffic

system 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 proposed above (Item 4 on the first list). A second stage in the development of the performance monitoring system will be the actual development of this software.

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APPENDIX

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, this data is 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.