Title
Assessing the Value of TMCs and Methods to Evaluate the Long Term Effects of ITS: Measuring Congestion, Productivity and Benefit Flow from Implementation

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Assessing the Value of TMCs and Methods to Evaluate the Long Term Effects of ITS: Measuring Congestion, Productivity and Benefit Flow from Implementation

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Final Report

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ABSTRACT

The study carries out an evaluation of TMCs (traffic management centers) using three methodologies; case studies, performance based regressions and time series analysis. The study is an extension of previous work that assessed the contribution of different types of intelligent transportation investments and initiatives. However, this research sought to distinguish the separate contributions of the ITS investments from the synergies of integration under a traffic management center. Secondly, the research investigated the time dimension of benefits where we investigated if there was an 'S' curve effect in which a change in the network due to an ITS investment or the introduction of a TMC lead to benefits distributed over time. The distribution was important to evaluating ITS investments. If one measured the impact of the investment too soon, in the disequilibrium period, it would underestimate the true contribution of the investment or change in process or management strategy.

We found the institutions that affect TMC operations with their designation of responsibilities, who can do what, when and where, requires change before the TMC can be an effective addition to the management of the transportation network. TMCs represent an integration of hardware and people and that process and management were most important in ensuring the TMCs had added value.

Our performance related regressions used levels and changes in congestion (measured by a congestion index) and changes in VMT for autos and trucks. We found that for auto VMT ramp meters were more important than CMSs in improving the system. This was, more VMT can be obtained from the system, holding congestion constant, with ramp meters. We found that TMCs had no statistical impact on auto VMT. In the case of truck VMT, the results were just the reverse; CMSs appeared to be more important than ramp meters in improving system efficiency when efficiency was measured by extracting more truck VMT from the system, holding congestion constant. As with the auto results, TMCs were not significant in the analysis.

The regression using the congestion index found ramp meters appear to be 4 times as effective as CMSs. TMCs as before were not statistically significant in affecting congestion. Overall the model did not have a lot of explanatory power in sorting out the differences in congestion among counties or what the underlying contribution is of ITS relative to investments. But it is evident that among conventional congestion relief measures maintaining infrastructure (roads) is more effective than expanding capacity. It also appears that ramp meters and CMSs, indicators of improved network management are more effective in reducing congestion than are expanding the network.

KEYWORDS: traffic management, ITS, productivity, ITS Evaluation, ITS Benefit-Cost, Traffic Management Center

INTRODUCTION

Over the last four years we have learned a good deal on the evaluation of costs and benefits of the introduction of ITS services. In all the evaluations the analysis is conducted in a partial equilibrium setting or framework, meaning that the effects are measured as occurring wholly within the transportation sector. In this research we pursue two integrated streams of research. First, we examine the 'integration' of ITS applications - ETCs, ramp metering, FSPs, ATIS and traffic signals - in the form of TMCs. Our purpose is to assess the gains from synergies across the joint application of ITS projects. In the second research direction we examine the effect of ITS investments on the broad economy through their impact on changing systems, markets and networks.

This research builds on earlier research which focuses on methodological and measurement issues in benefit cost assessments of ITS applications. The important contributions of this work are not only providing methods for calculating benefits and costs but also an empirical assessment of the set of projects that have been implemented. In all of this work, as well as most other project evaluation studies, two strong assumptions are made. First, the project is implemented successfully and second the impact of the transportation project is felt wholly within the transportation choice sets of consumers and producers. In the first of these assumptions, a project could potentially be declared unsuccessful when the technology may in fact be quite appropriate and potentially provide significant benefits, but the way it was implemented may have lessened some of the potential benefits. The study of implementation is one of understanding processes and how people integrate with new methods and technologies.

In trying to understand the implementation process requires detailed case studies of ITS and TMC applications. There are three steps needed, first how did the decision to adopt ITS and TMC in particular take place, second how was the introduction carried out within the agency or district and third, how was the value and performance of the application assessed? The set of three steps represents the process of implementation; selection of project, integration of the investment into the firm or agency and a final evaluation of how it is contributing and what might need to be changed in order to improve the return from such an investment.

Understanding process requires case study. How things are done, how decisions are made, where the pressures are and what resources are mobilized to facilitate the investment are all real concerns. There will also be groups, stakeholders who may be or feel threatened by such a proposal and others in an organization who can affect the extent of success of the investment in a TMC. Failure to communicate the purpose, means and anticipated outcomes of such an investment may simply lead to people ignoring it and hence, inadvertently, diminishing its overall success. In a case analysis it is the process that is at issue. Selecting three or four ITS applications that include TMCs in all or most cases provides a reasonable portfolio to reveal lessons and success drivers as well as factors that lead to less success.

In our investigation, the emphasis is on the measures of benefits that arise from the integration of ITS investments (or their effects) into the consumption activities of individuals and the production processes of firms. In all previous analysis, any changes to the transportation system are assessed in terms of modal, route or travel timing shift. All of the changes are assumed to occur wholly within transportation choices with no impact on other activities that affect households or individuals. Yet we know that changes in the service levels and costs of transportation influence many other choices we make in our lives including housing location, entertainment and social activities, education etc.. These are more general impacts and we know from other research that the results from a partial equilibrium analysis, the traditional approach, can differ markedly from a more general equilibrium analysis such as proposed here.

The case studies provide a context for our subsequent statistical modeling. We estimate statistical models using data from California to empirically measure the impact of TMCs.[1] The parameters available from these models provide input into the models that will provide broader measures that encompass the full general equilibrium affects of the introduction of ITS. In the statistical modeling we are attempting to understand three different tissues. First, how does the integration of ITS applications in the form of TMCs affect performance and are there differences in the combination of ITS applications? Second, how do measures of input performance, greater efficiency for example, compare to measures of output performance, reduced congestion or more output from a given network or infrastructure investment, for example.

RECENT LITERATURE

Banks and Kelly prepared a report in 1997 on the performance measurements of ITS and TMCs. This report was to examine the current state of TMCs in California, specifically, the San Diego and Orange County systems. It was to also analyse the performance measurement of Caltrans' TMCs.

In order to determine the benefit of TMC systems, more credible and quantitative performance measurements were sought. Upcoming large scale investments required more proof that the benefits resulting from implementation would exceed the cost. Performance measurement would be a quantitative meter based on system output, quality of service, environmental impact or similar features.

The study was conducted with two phases. The first was a broad-based assessment of performance measurement, including potential issues and measures of effectiveness. The second was to apply what was learned to the cases of San Diego and Orange County. (also known as Caltrans districts 11 and 12)

Firstly, objectives were required for why performance measures were desired. Objectives included the evaluation of potential investments in TMCs, the justification and rationalisation of operating budgets to TMCs, monitoring TMCs, reporting results to the public and advancing knowledge on traffic systems.

With objectives in place, the next step was to determine the objects on which the performance measurements would take place. These objects included the overall highways system, TMCs and other Caltrans units involved in traffic management as well as TMC functions. TMC functions are

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[1] Our initial plan was to integrate data from several sites in California with data from sites in other states to provide a richer information set. It was not possible to complete this because the data are organized in a different way in different states. The information could not easily be placed on a commensurate basis.

the items by which the centre can help to manage traffic systems. These include ramp metering, incident management, traveler information (changeable overhead message signs, highway information radio), motorist assistance, and information dissemination.

A Measure of Effectiveness (MOE) is defined as "a *quantitative measure that is intended to express the degree to which an objective is met." The objectives considered here are those of the TMC, specifically, the minimisation of congestion, minimisation of accident rates and minimisation of environmental impact.* The above are affected first and foremost by traffic demand, but secondly by TMC workload and TMC functions.

TMC functions each have specific objectives in order to reach the overall goals of the TMC. For instance, ramp metering is designed to reduce the flow of traffic on to the freeway so that overall traffic flow is improved, thus decreasing congestion. Traveler information such as changeable overhead messaging signs are designed to warn motorists of hazardous conditions and to divert traffic around areas of congestion. Data collection and dissemination is to provide information to researchers to study and understand traffic flows such that further measures can be designed to improve traffic flow.

There are numerous potential MOEs. These can include air pollution rates, energy consumption, incident count, motorists assisted and customer satisfaction. The major MOEs, however, are travel time and related measures, ramp delay, traffic volume and related measures, accident rates, traffic information accuracy, incident clearance time and equipment status.

Proper measurement techniques are required to quantify MOEs. Travel time can be measured using three approaches: estimating from spot speeds, estimating from cumulative flow distributions and measuring times directly. The first two can be done using loop detectors, while the third can be done using a transponder or similar method. Ramp delay can only be done using manual queue counts. Traffic volume can be determined using loop detectors. Accident rates are taken from the TASAS database, which is the number of police reported accidents. As a result of all accidents not reported to police, the TASAS number is probably an underestimation. Traffic information accuracy can be measured by verifying data and comparing it to loop detector generated data. Incident clearance times can be taken from computer-aided dispatch or incident logs of local TMCs. Lastly, equipment status can be determined as the fraction of equipment not working properly.

The two centres examined in the report are San Diego and Orange County. For each of the major MOEs, the specific applications to the centres are discussed below. For travel time, both areas use loop detection. Ramp metering differs between SD and OC, with the latter utilizing manual queue count while the former discontinued its queue counts because of the expense involved. Traffic volume was computed using loop detectors in each city; however, OC had a better coverage area than SD. Traffic information accuracy in both centres was to improve with a newly automated system to detect loop detector errors, however, other areas that require manual checking will not improve, as there is a trend towards reducing staff at Caltrans. Incident clearance times are stored in computerized logs, but actual time requires manual calculation and neither centre is willing to do this. Equipment status is successfully monitored by NET software in OC, and there are plans to implement such software in SD.

Banks and Kelly make a number of conclusions in their report. Firstly, they state that performance measurement is not an appropriate way to establish the entirety of benefits from a TMC. The most appropriate applications of performance measurement are in the evaluation of changes or new investment in TMC functionality and continuous monitoring to detect changes in traffic systems. In most cases, the authors conclude, the best study design is comparing before and after data, as this does not require continuous data collection.

Nevertheless, there are areas of potential improvement. The use of single loop detectors does not measure speed directly. Furthermore, actions that can improve measurement effectiveness include the "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."[2] Banks and Kelly further conclude that San Diego and Orange County are in the process of developing sophisticated traffic data systems, but there is still work needed to be done.

To address the areas of weakness developed in the report, Banks and Kelly make a number of recommendations. They believe that Caltrans should develop a policy for evaluation of investments in TMC functionality. To ensure accuracy of data, Caltrans should develop quality control systems for traffic information, as well as compare loop detector based time estimated with actual travel times. Further to this, Banks and Kelly recommend that PATH continue to conduct research evaluating non-loop based measures of travel time. Lastly, the authors recommend that the areas of traffic surveillance be expanded to include a greater number of highways within the TMC's area.

The 1993 report by Loral AeroSys examines the state of Traffic Management Centres (TMCs) at the time of the writing. Discussed are individual cities' TMCS as well as Advanced Traffic Management Systems (ATMS) with respect to their components and expected development over the next twenty years. Furthermore, generalized conclusions about the state of Intelligent Traffic Systems are reached.

ATMS are the next step in the current TMC system. When a TMC becomes mature and complex, able to handle more issues simultaneously, it can be considered an ATMS. These systems should be an encompassing catchall, able to handle all aspects of a transportation system. To accomplish this, the ATMS must be able to collect real time traffic data through area-wide surveillance and detection, and provide integrated management of functions pertaining to ITS, including demand management and ramp metering. As well, ATMS should be able to provide rapid response to incidences (e.g. accidents, other traffic stoppages) and have proactive strategies with traffic flow, which include route guidance and pre-trip planning. ATMS must be able to provide interface to IVHS components such as ATIS, ARTS, CVO and AVCS, as well as non-IVHS components like police and fire departments. Lastly, the database must be in a unified structure to promote efficiency.

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[2] Banks and Kelly

In order to attain the ATMS, use of advanced technologies is required. These include advanced traffic surveillance and control, as well as models of traffic flow. Human factors and system integration also need to be considered.

A TMC will engage in the following activities: Receiving and processing surveillance inputs, executing traffic models, panning and monitoring of traffic control strategies and disseminating travel information.

Traffic surveillance is the process by which the TMC gathers information and data on traffic. Methods commonly used in this process include: "Inductive loop detectors (sensors), video Detection and Closed-Circuit Television (CCTV), infrared sensors, direct observation (police, public works, etc.), vehicle Probes, Aerial surveillance, Motorist reports through call boxes and cellular phones." With proper information, the TMC is able to determine actions necessary to maintain decent traffic flow.

Traffic is managed using Traffic Control Systems. These are directly managed by the TMC and can take many different architectural forms. No matter what the system is, the focus should be on proactive solutions to problems, rather than reactive. By monitoring for traffic problems or incidents, a traffic control system should reroute traffic and inform the motorist of problems using changeable message overhead displays, so that she may take an alternate route. In fact, by implementing an IVHS system, congestion can be reduced by 20%

Another way in which traffic can be controlled is through ramp metering. In this, only a specific number of vehicles are allowed on to a freeway, based on traffic flow and the capacity of the freeway. While this creates delays on the on-ramp for motorists, overall travel times decrease as a result of better freeway management.

Loral AeroSys examined a number of TMCs themselves, while also citing research on others. Cities in the report included Los Angeles, Washington D.C. and Toronto <expand>.

The most common surveillance method was loop detection, although most had a closed circuit TV system as well. As a result, incident detection is completed using loop detection, where traffic information is fed through an algorithm and compared to a 'proper' (i.e. incident free) set of information. If there is a discrepancy, then an 'incident' has been adjudged to have happened, and the proper authorities are dispatched and traffic control methods are set in place.

Control systems at the time of the report's writing are generally UTCS or derivatives. Some use only time of day systems, others use traffic response and CIC.

Specific results of the implementation of ITS and TMC in Los Angeles are remarkable. Travel time down 18%, intersection delays are down 44%, stops have been reduced 41% and air emissions were reduced by 35%. Overall, the benefits outweigh the costs with a 23:1 ratio.

At the end of the report, the authors give some conclusions. Firstly, "there is a uniform lack of standards for interfaces and data management, and there is recognition that these are needed". Secondly, there is "minimal automated support for analysis, particularly online decision support, and integrated management of transportation services." Thirdly, there is a "lack of automated interfaces to non-IVHS systems." Fourthly, overall there is "general satisfaction with the operational capabilities of UTCS-based systems." Fifthly, "the common belief by TMC managers in the effectiveness and success of their operations, and the desire to improve through a selective application of new technologies and products." Lastly, "TMC managers are beginning to appreciate the advantages of an open systems architecture."

METROPOLITAN TRANSPORTATION MANAGEMENT CENTER CONCEPTS OF OPERATION

This study of October 1999 was conducted by the Intelligent Transportation Systems division of the United States Department of Transportation. Designed with the purpose of guiding municipalities in their implementation of Intelligent Transportation Systems, this study examines a number of pre-existing ITSs, while discussing lessons learned from the systems.

The study examined each city on a number of factors. Cities examined in this study were the following: Atlanta, Boston, Detroit, Houston, Long Island, Milwaukee, Phoenix and Toronto. For each of the cities, factors such as design and implementation, operation and maintenance were considered. Furthermore, the mission, goals and vision of the system are examined, as is need and purpose.

Boston's system is properly known as the Integrated Project Control System. Considered to be one of the most complex, yet reliable systems, it covers the 7.5 mile Boston central freeway and tunnel artery. Its operation consists of vehicle detectors, overheight detectors, closed circuit television, lane control signals, and variable message signs communicating over a fiber optic network.

In Toronto, there are three TMCs. There are two smaller centers along with the COMPASS Downsview TMC, which is the focus of this report. The Downsview TMC balances traffic between the express and collector lanes of the 401 using vehicle detectors, closed-circuit television, and variable message signs communicating over a fiber optic network. A 1994 evaluation showed that it prevents 200 accidents per year while increasing average speed by 7-19%.

Long Island's system, named INFORM, uses vehicle detectors, closed-circuit television, traffic signals, ramp metering, and variable message signs to identify areas of congestion and attempts to minimize the duration by informing motorists. INFORM has been successful, citing a 13% increase in average highway speed, despite a 5% increase in traffic. Furthermore, the number of locations with a speed of less than 30MPH in the morning rush hour decreased by 50%.

Detroit's Intelligent Transportation System Center originally managed 32.5 miles but this is to expand to 180 miles of highway. The older system includes ramp meters, detectors, and closed-circuit television with communications via coaxial cable, while the newer system is expanded to include highway advisory radio, communication via microwave and spread spectrum radio to an OC-48 fiber optic network. There has been a 50% reduction in accidents and an 8% increase in speed along with a 40% reduction in delays.

Milwaukee's MONITOR system uses vehicle detectors, closed-circuit television, traffic responsive ramp metering with high occupancy vehicle (HOV) priority, freeway and arterial variable message signs, and highway advisory radio to manage traffic on its ‘incomplete freeway system.’ Overall, there has been a 14.8% reduction in accidents with significant improvements in travel time.

Atlanta’s NaviGAtor was designed to address congestion and related problems for the 1996 Olympics. This is accomplished by informing motorists of conditions ahead, allowing them to avoid problems. Vehicle detectors, closed-circuit television, variable message signs, and ramp meters communicating over a fiber optic and microwave network are all employed. Improved links with police and road clearing crews have been established, causing a 50% reduction in the time between the report of an accident and the dispatch of emergency crews.

The stated objectives of Phoenix’s TrailMaster are “to support optimum utilization of the freeway system, provide a safe and efficient environment for users, and ensure efficient utilization of ADOT resources.” To accomplish this, the system employs vehicle detectors, closed circuit television and variable message signs. According to the Arizona DOT, 21% of vehicles are diverted in the case of an accident, resulting in significant savings in vehicle-hours.

The TranStar system in Houston is a multi-agency endeavor, operating with the assistance of the DOT, the City of Houston, Harris County and Houston Metro. TranStar operates using variable message signs, highway advisory radio, loop detectors, closed-circuit television, lane control signals, ramp meters, a motorist assistance patrol, and an AVI-based congestion detection system. Benefits of TranStar are conservatively estimated to be five minutes per incident, totaling annual savings of 573,095 vehicle-hours.

A number of successful practices were identified in the areas of planning, system design and implementation, system operation, staffing, coordination between agencies and the media, and system maintenance. Under planning, most TMCs examined themselves after incidents, looking for areas to improve. As well, most TMCs appeared to be planning for the future, most notably Phoenix, who have a long-term plan, which includes a potential statewide TMC system in the years to come.

Successful practices that come from system design and implementation include improvements in computer reliability, which goes as far as Boston’s triple redundant system. Houston has found it effective to create a simulator before implementation of a new system to allow operators to get a ‘look and feel’ for it.

Operational successes included the ability of Detroit and Milwaukee to streamline their incident detection through 911 calls received in their buildings, which also housed law enforcement agencies. Other operational successes included Toronto, who pioneered the use of variable message signs and Milwaukee, who used portable detectors around construction sites.

Staffing is viewed as one of the most difficult components of TMC operation. As a result, acquiring and retaining quality employees is an important goal. Milwaukee has had success in employing college students, while Long Island is located central to three airports, and has had success in hiring former air traffic controllers. Sources for hires include community colleges, postings within the agency and agency surplus personnel. Common backgrounds of hires include Traffic Equipment Maintenance, Air Traffic Controllers, Radio Operators, Clerical/Administrative Personnel, Students and Dispatchers.

Co-ordination between agencies and the media is an important element of the operation of a TMC as it allows the most efficient and best service. In Milwaukee and Detroit, co-ordination with law enforcement officials is aided through having the same geographic location. Co-ordination with wreckers and accident removal firms is important as it allows for quicker incident clean-up times, and as a result has been pursued by many TMCs. Co-ordination with the media is also important, as a good relationship can be beneficial from a public relations standpoint.

System maintenance is required so that the TMC can function effectively. To accomplish this, many TMCs are engaging in preventative maintenance, both on newer and older systems. Configuration Management databases are being created, notably by Toronto and Boston. This database is a store of all data pertaining to the current hardware and software, for example, manufacturer, model and serial number.

Report by Loral AeroSys:

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CASESTUDIES

ANATOMY OF AN INCIDENT

0735 On eastbound Interstate 10 at La Brea a car clips the front of a van while changing lanes. The van careens into the median barrier and back out onto the freeway. A big rig, attempting to avoid the van jack-knifes and goes over onto its side blocking four lanes of traffic. Two cars, unable to stop hit the truck.

0737 Alerted by a cell phone user, a California Highway Patrol dispatcher enters preliminary crash information into their Computer Aided Dispatch (CAD) system. A CHP unit is dispatched. CHP requests Freeway Service Patrol (FSP) truck, which is in the area, to go to the site and report.

0740 Data from the loop detectors imbedded in the freeway surface near the crash begin to reflect the abrupt change in traffic flow. This change is picked up by the traffic management software and a flashing red icon appears upstream from the accident site on the large Automatic Traffic Management System (ATMS) wall display map in the LA Transportation Management Center (TMC). The TMC operator check the CHP CAD display which shows a crash reported at this location. He then activates nearest CCTV camera to investigate.

0741 While the CCTV camera shows the traffic at a standstill, it is too far away to see the actual crash site. TMC operator checks to see if there are any Changeable Message Signs (CMS) upstream from the site and continues to monitor CAD screen.

0745 FSP truck arrives and notifies CHP that multiple lanes are blocked and that a large truck is overturned.

0748 CHP unit arrives and calls for ambulance, fire equipment, and additional CHP units. Confirms lane blockage. Information is entered onto CAD system.

0750 With confirmation from CCTV and CHP CAD, and realizing that this crash will take hours to clear, the TMC operator notifies the on-call senior Traffic Management Team (TMT) leader who, on learning the seriousness of the incident, decides to roll a team and instructs the TMC operator to assemble a four person team by contacting on call personnel. Since this crash will have a major impact on the surface streets paralleling Interstate 10, LA's Automated Traffic Surveillance and Control unit, which can control signal timing, is notified.

0750 CHP issues a sigalert (an alert to the media and motoring public of a major, unplanned incident that will affect one or more lanes for 30+ minutes, causing congestion or delays. They are issued by the CHP Communications Center).

0755 Operator sends preliminary pager message to senior Caltrans managers and officials.

0755 Appropriate messages posted on fixed CMS upstream from crash as well as on connecting freeways. (Rule of thumb for posting message on CMS: incident likely to last more than 15 minutes and causing more than 1/4 mile of traffic backup.)

0800 Where necessary, TMC operator adjusts impacted ramp meters. While most ramp meters are traffic responsive, they can be overridden from within the TMC.

0815 TMT arrives on scene and set up portable CMSs to divert traffic. Travelers first see advisory truck with sign, then a matrix truck with a queue message to merge. Most of the sign messages are canned. One sedan driver is ahead of queue managing the two trucks. Second sedan driver keeps in contact with TMC as eyes and ears at the scene. Driver will work with TMC to come up with appropriate CMS messages. TMT stays on scene until traffic reaches free flow.

1245 All lanes cleared and vehicles removed. TMT exits the area. Fixed location CMS are changed from “Lanes Blocked” to “Traffic Jammed”.

1400 Traffic flow returns to normal. CMSs are cleared.

INTRODUCTION

The focus of this report will be the Los Angeles, Sacramento, and Bay Area TMCs. We will begin, however, by looking California TMCs in general. These facilities are the focal point for maximizing traffic flow on the current freeway system and reducing traffic congestion through coordination with the California Highway Patrol. Moving people out of cars, developing transportation alternatives, debating the merits of HOV lanes or new connectors, and all other factors related to matching roadway supply with demand are irrelevant to the quotidian task of maximizing throughput. The latest in electronic technologies are being used to aid in carrying out the tasks of rapidly detecting, confirming, and responding to freeway incidents while managing the resulting congestion. These technologies include:(TMC Brochure)

- Wire Loop Detectors (Vehicle Detection Stations -imbedded in freeway lanes for mainline surveillance; and Ramp Metering Stations for mainline and on/off ramp surveillance)
- Microwave Vehicle Detection System
- Fiber Optic Communication System
- Closed Circuit Television Cameras (CCTV)

•Ramp and Connector Metering

•Changeable Message Signs (CMS)

•Highway Advisory Radio(HAR)

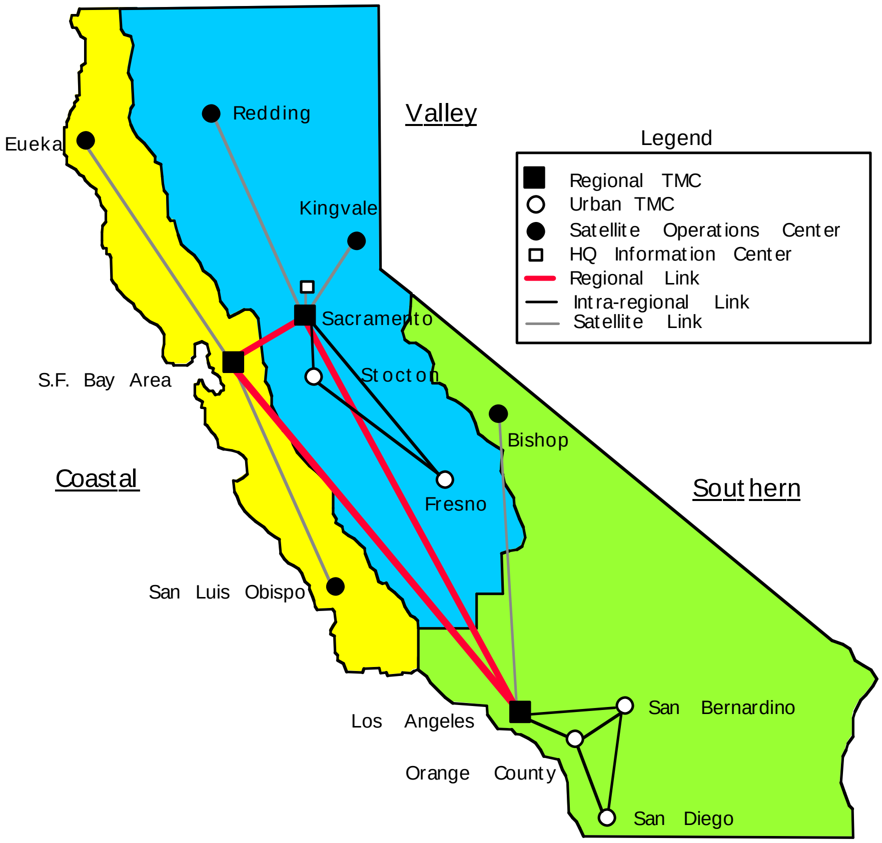
•Advanced Traveler Information Systems (ATIS)

There are currently eight transportation management centers (TMCs) in operation throughout California (Figure 1) which form the foundation for the Intelligent Transportation Systems (ITS) deployment within the state. As the center for the collection and dissemination of transportation information, these TMCs are responsible for the management of the state highway system and the delivery of transportation information to the motoring public

Three regions have been established (Coastal, Valley, Southern), each of which will contain one TMC that coordinates the efforts among a variety of Urban TMCs, Satellite Operations Centers (SOCs), Mobile Operations Centers (MOCs), and Headquarters Management Centers (Nuaimi, 1999).

Figure 1

California Transportation Management Centers

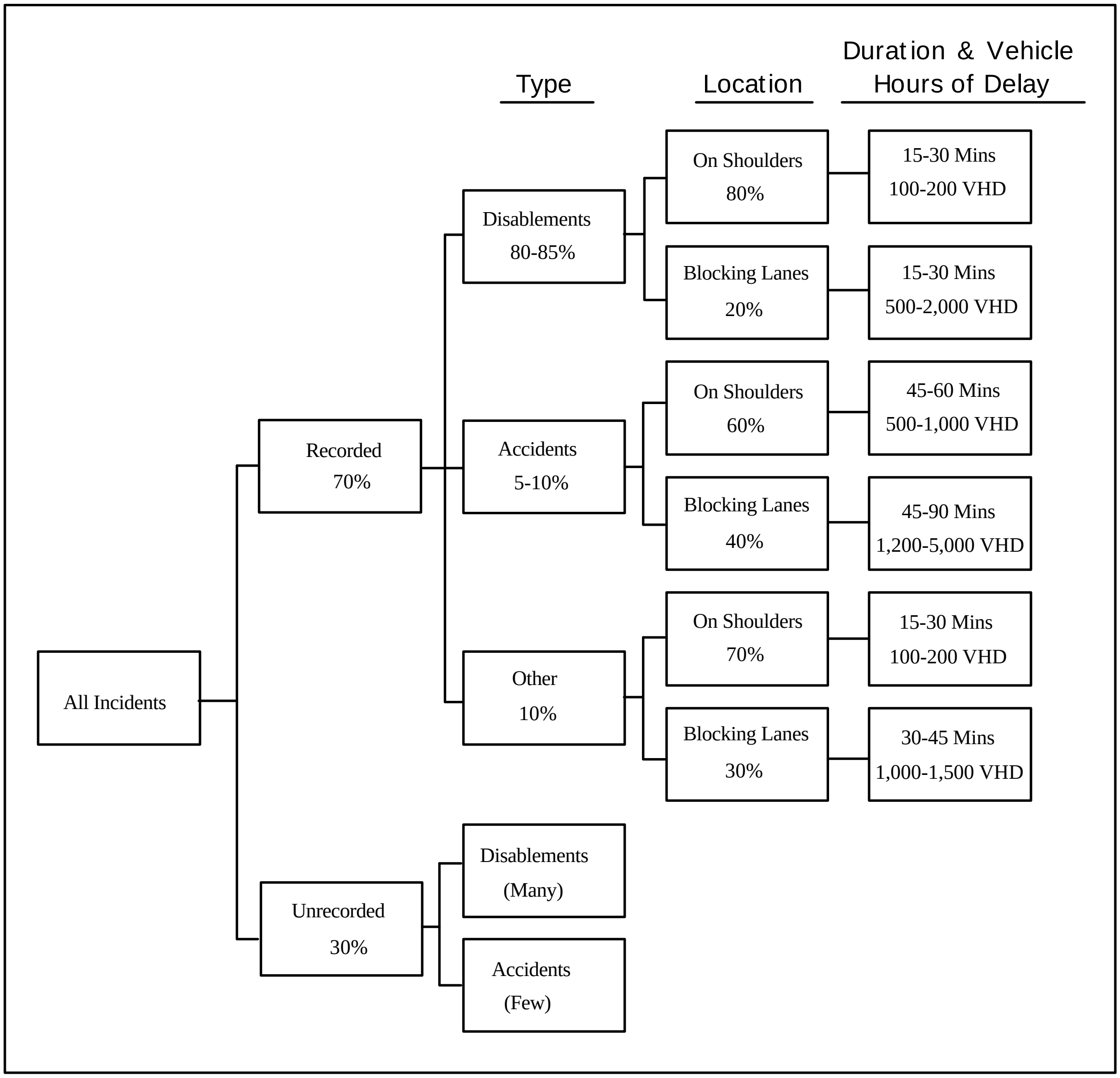


Source: Nuaimi, 1999

While urban freeways make up less than 2.4 percent of the total urban highway miles they carry approximately 20 percent of the traffic nationwide. Congestion on this roadway system can occur under recurring conditions (i.e., capacity limitations) or can be non-recurring (caused by accidents or breakdowns). It has been estimated that as much as 60% of all freeway congestion (increasing to 70 percent by the year 2005, at a cost to the U.S. public of over $75 billion in lost productivity and the waste of over 8.4 billion gallons of fuel,[Pearce and Subramaniam, 1998]) is under non-recurring conditions which suggests that the key strategy for reducing congestion in major urban areas is to clear incidents and accidents as quickly as possible. As shown in Figure 2, 80 to 85 percent of recorded incidents are vehicle disablements while 5 to 10 percent are due to accidents (Meyer, 1997).

Figure 2

Profile of Incidents By Type



Source: Cambridge Systematics and The ATA Foundation 1996

Although traveler delay is the problems most often associated with highway incidents, a 1982 Minnesota Department of Transportation study found that 13 percent of all peak period crashes were the direct result of a previous incident. Worse still, the severity of secondary crashes is often greater than that of the original incident. The longer an incident is in place, the greater the exposure to additional crashes. A 1995 analysis of collision statistics (Volpe NTSC) on several arterials and expressways in California showed that secondary crashes represent an increase in collision risk of over 600 percent (Farradyne, 2000).

Even minor crashes and disablements can have a large effect on traffic. Table 1, illustrates that an incident or unplanned work zone activity reduces freeway capacity by an amount far greater than the physical reduction in roadway space caused by the incident (Farradyne, 2000).

Table 1:

Percentage Of Freeway Capacity Available Under Incident Conditions

Number of Freeway Lanes In Each Direction	Shoulder Disablement	Shoulder Accident	Lanes Blocked		
			One	Two	Three
2	0.95	0.81	0.35	0.00	N/A
3	0.99	0.83	0.49	0.17	0.00
4	0.99	0.85	0.58	0.25	0.13
5	0.99	0.87	0.65	0.40	0.20
6	0.99	0.89	0.71	0.50	0.25
7	0.99	0.91	0.75	0.57	0.36
8	0.99	0.93	0.78	63	0.41

Source: 1996 Traffic Control Systems Handbook

In the Transportation Research Board's synthesis of transportation management center's functions, Kraft (1998) lists the following expected systems related benefits of highway TMCs:

Better incident management in terms of reduced incident response times; incident detection times; and incident clearance times to restore normal operating conditions, limiting the possibility of secondary accidents

Better congestion management, traffic management, and traffic diversion in response to traffic and weather related incidents; major events; route and alternative route comparisons based on improvement and service level indicators; mitigating the effects of recurring and non-recurring congestion through various congestion management techniques; large scale construction activities.

Improved information dissemination to emergency services and their vehicles; information service providers; traveling public; media; public agencies; private organizations.

- Maintained and/or improved overall safety on the transportation system.

- Reduced travel delays and times related to incidents; ramp metering controls.

- Reduced number of incidents and accident rates (including secondary accidents).

- Improved air quality through pollutant reduction; fewer vehicle emissions.

Increased highway efficiency through transportation demand management/system management strategies such as HOV lanes

- Increased energy and fuel savings

- Enhanced efficiency of the transportation infrastructure.

- More efficient snow removal.

- Improved signal coordination, analysis, and timings to create continuous and progressive traffic flow.

TMCs are highly dependent on technology to accomplish their mission and ever expanding geographical coverage requires that they employ modern communications and computing resources. The integration of a variety of field devices and control center hardware as well as the compatibility of new systems with legacy systems (which often contain significantly different types of technology) is a major undertaking. TMC management thus faces a daunting challenge of implementing, operating, and maintaining not only a complex transportation environment, but also a mass of complex and rapidly evolving technology (Center for Urban Transportation Research, 2001).

INCIDENT DETECTION AND VERIFICATION

Table 2 shows the various sources of incident reports as well as the primary recipients. While incident detection used to be one of the major tasks of TMC operators, this is no longer the case. With cell phones everywhere, most incidents that could have an effect on traffic are reported within minutes, with some Incident management programs reporting the percentage of incidents detected by cell phone callers to 911 or other numbers as high as 90%. In areas with dense traffic the time to detect incidents is nearly instantaneous (Farradyne, 2000).

Table 2

Incident Detection Sources

Source	Primary recipient of information from each source
911 Calls	CAD
Call boxes	CAD. Dispatcher will enter into CAD, and dispatch FSP if appropriate.
Public telephone lines	CAD, TMC
Caltrans field personnel	TMTs, (report stalled vehicles, debris in roadway; etc.) via cell phone or two way radio
CHP field personnel	CAD
Freeway Service Patrol	CAD
Allied Agencies	TMC
Caltrans Two-way radio	From TMTs to TMC
CHP Two-way radio	CAD. CHP is always the lead on the incident scene.
Media	Calls from media and from monitoring traffic reporting service via AM radio.
CAD	Primary incident detection. 3,000+ log entries a day.
Electronic Automatic Incident Detection (AID)	TMC - Data from loop detectors feed AID algorithm in ATMS

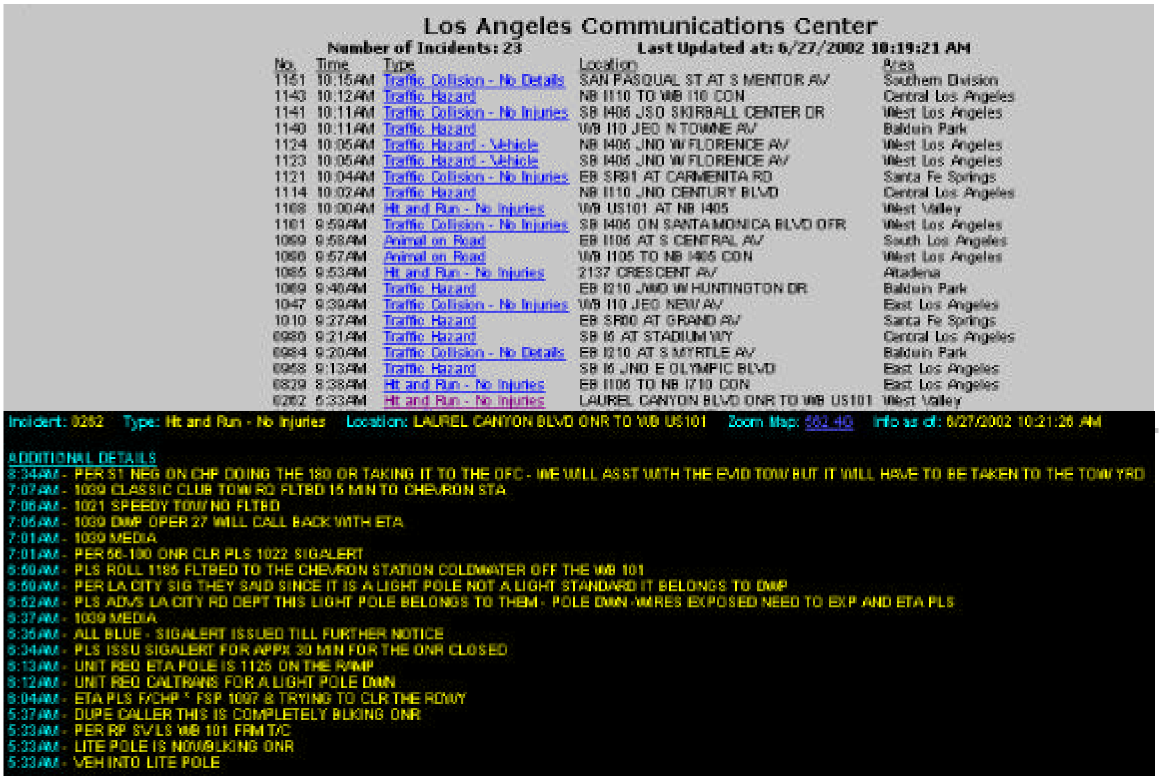
Source: Booz-Allen

The CHP's Computer Aided Dispatch (CAD) is the main source of incident notification for California's TMCs. Figure 3 shows a screen, available on the internet at http://cad.chp.ca.gov, that is similar to the one available to the TMC operators (since the actual display may contain sensitive information it is available only to CHP personnel and the TMC operator). Each incident reported to the CHP is displayed. By selecting a specific incident, its status as well as additional information are shown (bottom part of screen). In this case, the incident selected is a hit and run reported at

5:33 AM involving a vehicle into a light pole on the Laurel Canyon on ramp to westbound highway 101.

Figure 3

CAD Screen



Los Angeles Communications Center

Number of Incidents: 23 **Last Updated at: 6/27/2002 10:19:21 AM**

No.	Time	Type	Location	Area
1151	10:15AM	Traffic Collision - No Details	SAN PASQUAL ST AT S MENTOR AV	Southern Division
1143	10:12AM	Traffic Hazard	NB I110 TO WB I10 CON	Central Los Angeles
1141	10:11AM	Traffic Collision - No Injuries	SB I405 JSO SKIRBALL CENTER DR	West Los Angeles
1140	10:11AM	Traffic Hazard	WB I10 JEO N TOWNE AV	Baldwin Park
1124	10:05AM	Traffic Hazard - Vehicle	NB I405 JNO W FLORENCE AV	West Los Angeles
1123	10:05AM	Traffic Hazard - Vehicle	SB I405 JNO W FLORENCE AV	West Los Angeles
1121	10:04AM	Traffic Collision - No Injuries	EB SR91 AT CARMENITA RD	Santa Fe Springs
1114	10:02AM	Traffic Hazard	NB I110 JNO CENTURY BLVD	Central Los Angeles
1108	10:00AM	Hit and Run - No Injuries	WB US101 AT NB I405	West Valley
1101	9:59AM	Traffic Collision - No Injuries	SB I405 ON SANTA MONICA BLVD OFR	West Los Angeles
1099	9:58AM	Animal on Road	EB I105 AT S CENTRAL AV	South Los Angeles
1098	9:57AM	Animal on Road	WB I105 TO NB I405 CON	West Los Angeles
1085	9:53AM	Hit and Run - No Injuries	2137 CRESCENT AV	Altadena
1069	9:46AM	Traffic Hazard	EB I210 JWO W HUNTINGTON DR	Baldwin Park
1047	9:39AM	Traffic Collision - No Injuries	WB I10 JEO NEW AV	East Los Angeles
1010	9:27AM	Traffic Hazard	EB SR60 AT GRAND AV	Santa Fe Springs
0990	9:21AM	Traffic Hazard	SB I5 AT STADIUM WY	Central Los Angeles
0984	9:20AM	Traffic Collision - No Details	EB I210 AT S MYRTLE AV	Baldwin Park
0968	9:13AM	Traffic Hazard	SB I5 JNO E OLYMPIC BLVD	East Los Angeles
0829	8:38AM	Hit and Run - No Injuries	EB I105 TO NB I710 CON	East Los Angeles
0262	5:33AM	Hit and Run - No Injuries	LAUREL CANYON BLVD ONR TO WB US101	West Valley

```
Incident: 0262   Type: Hit and Run - No Injuries   Location: LAUREL CANYON BLVD ONR TO WB US101   Zoom Map: 562 4G   Info as of: 6/27/2002 10:21:26 AM

ADDITIONAL DETAILS
8:34AM - PER S1 NEG ON CHP DOING THE 180 OR TAKING IT TO THE OFC - WE WILL ASST WITH THE EVID TOW BUT IT WILL HAVE TO BE TAKEN TO THE TOW YRD
7:07AM - 1039 CLASSIC CLUB TOW RQ FLTBD 15 MIN TO CHEVRON STA
7:06AM - 1021 SPEEDY TOW NO FLTBD
7:06AM - 1039 DWP OPER 27 WILL CALL BACK WITH ETA
7:01AM - 1039 MEDIA
7:01AM - PER 56-100 ONR CLR PLS 1022 SIGALERT
6:50AM - PLS ROLL 1185 FLTBED TO THE CHEVRON STATION COLDWATER OFF THE WB 101
6:50AM - PER LA CITY SIG THEY SAID SINCE IT IS A LIGHT POLE NOT A LIGHT STANDARD IT BELONGS TO DWP
6:52AM - PLS ADVS LA CITY RD DEPT THIS LIGHT POLE BELONGS TO THEM - POLE DWN -WIRES EXPOSED NEED TO EXP AND ETA PLS
6:37AM - 1039 MEDIA
6:36AM - ALL BLUE - SIGALERT ISSUED TILL FURTHER NOTICE
6:34AM - PLS ISSU SIGALERT FOR APPX 30 MIN FOR THE ONR CLOSED
6:13AM - UNIT REQ ETA POLE IS 1125 ON THE RAMP
6:12AM - UNIT REQ CALTRANS FOR A LIGHT POLE DWN
6:04AM - ETA PLS F/CHP * FSP 1097 & TRYING TO CLR THE RDWY
5:37AM - DUPE CALLER THIS IS COMPLETELY BLKING ONR
5:33AM - PER RP S/LS WB 101 FRM T/C
5:33AM - LITE POLE IS NOW BLKING ONR
5:33AM - VEH INTO LITE POLE
```

When an incident appears that could affect traffic it can be verified by several means including Caltrans field personnel, FSP operators, CCTV, or on-scene CHP personnel. As the operator waits for confirmation (for those incidents not visible from a CCTV camera), he will check to see if any changeable message signs (CMS) or highway advisory radio (HAR) stations are available upstream from the incident site.

TMC ACTIONS

Once confirmed as an incident that will affect traffic, the TMC operator must decide, based on vehicles involved, lanes blocked, and location, what action to take. At the least, CMS will be activated. In addition, for serious incidents, including blockage of half the lanes for extended periods, hazardous material spills, overturned trucks, and natural disasters affecting a freeway, a traffic management team (TMT) must be notified. At the team's discretion, portable message signs can be moved into position and traffic diverted. While the TMC will keep the team abreast of any new developments and respond to any requests, once called, the team operates independently of the TMC.

In addition to calling a TMT for a serious incident, the TMC operator will activate a pager system that can transmit a message to a predetermined list of people, usually local Caltrans management and various members of the media. If there is a highway advisory radio (HAR) station nearby that could be of use to travelers on the affected freeway, the operator will record a message via the telephone and activate the station and sign telling travelers to tune to a specific frequency.

Tests have shown the willingness of motorists to respond to incident-related travel information from CMS and HAR as well as in-vehicle sources. In its first year of operation, TransGuide (San Antonio) noted an increase from 33 percent to 80 percent in the portion of motorists who had noticed and complied with CMS messages. Additionally, the number of San Antonio motorists who said that they used alternate routes during incidents increased from 45 percent to 71 percent (Pearce and Subramaniam, 1998).

Evaluations of user responses "have arrived at a uniform conclusion that travelers will act based upon information from a trusted and well-understood system that provides information of value. TransGuide's survey of motorist reaction to the information demonstrated a high level of acceptance...and a significant level of appreciation (71 percent felt they saved time) for the benefits they derived from it. No test has quantified isolated travel time benefits from incident management information alone, but motorists clearly felt that they derived an appreciable benefit from acting on the information, even in situations where information was only available en-route...and where diversionary routing was not utilized (Pearce and Subramaniam, 1998)."

As the incident winds down, CMS must be changed and finally turned off. To help keep track of current CMS status, the ATMS software can display a map showing all active signs. Additionally, a CMS log is kept manually .

REGIONAL TMCS

With the first, second, and fifteenth worst rush hour congestion in the country (Texas Transportation Institute, 2001), Los Angeles, San Francisco-Oakland, and Sacramento must do all they can to get incidents cleared as expeditiously as possible. The Transportation Management

Center (TMC), using advanced information, navigation, and communication technologies in conjunction with Advanced Traffic Management System (ATMS) software and operating procedures is the key to maximizing the performance of an urban transportation system. Statistics regarding equipment and coverage are shown in Table 1.

Table 3

Regional TMC Statistics

	Los Angeles	Bay Area	Sacramento
Monitored Centerline Miles	750	250	50
CCTV Cameras	343	217	26
Metered On Ramps	855	193	60
Metered Freeway Connectors	20	7	0
Changeable Message Signs	104	98	23
HAR Sites	23	21	15
Hours/Days of Operation	24/7	24/7	24/7
Loop Detector Stations	1,150	650	70
Microwave Detector Stations	0	150	70
FSP (Directional Miles)	439	416	106

LOS ANGELES

Caltrans' Los Angeles TMC, located on the second floor of 120 Spring Street, occupies part of an approximately 8,000 square foot room shared by Caltrans Maintenance, and Freeway Service Patrol dispatch. The TMC has been at this location since December, 1998. The TMC operates 24 hours a day, seven days a week utilizing three shifts: 6 AM – 2:30 PM, 2:00 PM – 10:00 PM, and 10:00 PM – 6:00 AM. There are two fully equipped operator stations, each with a CPU, CAD screen, and two ATMS monitors. There are two additional operator stations that lack the CAD screen.

The front wall of the room has of a large interactive map of the District 7 freeway system made up of four projection screen screens tied into the ATMS, as well as two projection screens and 12 standard video monitors on which can be displayed output from any CCTV camera.

The LA TMC's primary area of coverage is Los Angeles and Ventura counties which have a combined 616 miles of freeway and a total average of 110.6 million vehicle miles of travel per day. During a typical rush-hour, the three agencies located in the TMC have a total of approximately 17 personnel as shown in Table 4. When there is a third operator on duty, since there are only two CAD equipped stations, that person can perform such duties as putting up CMS messages, sending duty and information pages, calling TMT out, and break relief.

Table 4

Los Angeles TMC Personnel

Organization	Job Description	Number
Caltrans	TMC supervisor	1
	TMC lead person	1
	TMC operator	2-3
	Maintenance Dispatch Supervisor	1
	Maintenance Dispatchers	2-3
Freeway Service Patrol	FSP Dispatch Supervisor	1
	FSP Dispatchers	5-6
CHP	CHP TMC Officer	1

BAY AREA

In the San Francisco Bay Area, Caltran's TMC has been located on the sixth floor at 111 Grand Avenue in Oakland since June, 2001. The main control room is approximately 2,000 square feet and has 19 workstations, four configured for Caltrans operators (with a CAD screen, one CMS computer and screen, one standard PC applications computer and screen, and one computer and screen for displaying CCTV pictures), two for CHP, 4 for Caltrans dispatchers, and one for Travinfo. During a typical rush hour there are 12 people on duty as shown in Table 5

The front wall of the center has 35 TV cubes or monitors, twelve of which display the ATMS map, 3 display commercial television stations (e.g., NBC, CNN, Weather), 4 display pictures from the cameras on the Bay Bridge, and 16 showing output from operator selected CCTV cameras.

Table 5

Bay Area TMC Personnel

Organization	Job Description	Number
Caltrans	TMC supervisor	1
	TMC operator	2
	Maintenance Dispatch Supervisor	1
	Maintenance Dispatchers	4-6
TravInfo	Operator	1
CHP	CHP TMC Officer	2

SACRAMENTO

Caltrans' Sacramento TMC, located 3165 Gold Valley Drive in Rancho Cordova, occupies part of an approximately 6,000 square foot room along with Caltrans Maintenance dispatch, CHP dispatch, and Freeway Service Patrol dispatch. The TMC, which has been at this location since January 2000, operates 24 hours a day, seven days a week utilizing three shifts: 4 AM – 12:00 PM, 12:00 PM – 8:00 PM, and 8:00 PM – 4:00 AM. There are five fully equipped operator stations, each with a CPU, CAD screen, and two monitors capable of displaying CCTV pictures, ATMS information, and any other program loaded on the PC (e.g.,.word processing). There is also one station dedicated to CMS input.

The front wall of the room has six large projection screens and six CRT monitors. The screens can be set to display ATMS information or output from any CCTV camera. During a typical rush hour there are usually 26 people on duty as shown in Table 6.

TRAINING

None of the TMCs have a set, formal training program for their new operators. Training is, for the most part, on the job. The length of the training period varies considerably from individual to individual since the backgrounds of new operators is so varied, some having extensive experience (e.g., former CHP dispatchers) and some having virtually none. All three TMCs make use of the simulator at Cal Poly, San Luis Obispo, but only Sacramento and Oakland require attendance.

Given the relatively small total number of operators at each TMC (eight in LA, nine in Oakland, and seven in Sacramento), the widely varying previous work experience, and the low operator turnover rate (the newest operator in LA has been on the job for two years, in Sacramento, a year and a half) it very well may be impossible to establish a formal training program that wouldn't have to be constantly revised without ever being used.

There is no formal operations manual at any of the three TMCs although each has accumulated an informal collection of reference materials. The Oakland TMC has a proposed operations manual that has been in draft status for several years.

RELATIONSHIP WITH CHP

The primary role of the CHP is as the supplier of CAD information directly to the TMC operator. This information is the key to the entire operation as virtually all incidents are "detected" from this source (as a result of cell phone 911 calls to the CHP being entered into the system) as well as a large number of verifications.

In general, the role of the CHP officers assigned to the three TMCs fall into two general categories: 1) liaison between Caltrans and the CHP and 2) taking calls from the media. Each of the TMCs is equipped with camera and lights for live broadcasts - directly from the operations area in the L.A. and Oakland and from a separate media room with a window facing the TMC control room in Sacramento. In Oakland, the two officers also take part in Bay Bridge security, monitoring the four cameras whose pictures are displayed on the large picture wall.

Table 6

Sacramento TMC Personnel

Organization	Job Description	Number
Caltrans	TMC supervisor	1
	TMC Associate Engineers	2
	TMC Operator	2
	Maintenance Dispatch Supervisor	1
	Maintenance Dispatchers	2
Freeway Service Patrol	Dispatch Supervisor	1
	Dispatchers	2
CHP	TMC Officer	1
	Media Officer (AM only)	1
	Dispatch Supervisor	1
	Dispatchers	12

Sacramento is unique in that CHP dispatch is located in the TMC control room (the new L.A. TMC will also house CHP dispatch). It is also the only TMC in which the on duty CHP officer acts as a regular TMC operator in addition to his other duties. In L.A. and in Oakland, the assigned officer is available a to Caltrans personnel as go-between if additional information is needed from the scene of an incident regarding scope and possible duration. Theoretically, using information from CCTV cameras and Caltrans field personnel, the officer might be able to assess the incident before the assigned CHP unit arrives on scene and advise CHP dispatch as to required equipment. This potential function appears to be utilized infrequently, if at all.

RAMP METERING

Virtually all of the ramp meters in L.A., the Bay Area, and Sacramento are controlled by locally responsive mainline detectors which gives them the ability to adjust their timing according to local freeway conditions. One major drawback to this system is the fact that it only adjusts for local traffic flow, readily allowing cars onto the freeway even if there is a major problem developing further downstream. In L.A. there is a new system, known as SWARM (system wide adaptive metering), being tested along one corridor, which overcomes this problem by monitoring and adjusting for conditions at all meter locations.

While metering rates are adjustable within certain parameters from within the TMC, this is almost never done as part of incident management. Instead, meter timing is set for long term conditions and adjusted to maximize freeway throughput under normal operating conditions.

CHANGEABLE MESSAGE SIGNS

In the L.A. area CMSs are used to inform drivers of current conditions only. Thus a sign warning of lanes closed ahead due to construction would not be displayed in advance (e.g., a planned lane closure later that day) but would be posted only when the construction actually began and the lanes were closed. CMSs are also used for current weather conditions (e.g., High Winds Ahead) but never for public service messages.

The only other time CMSs would be used is for large special events, such as the Rose Bowl Game, when fixed and, more often, portable CMS will be used to advise drivers where to exit the freeway for the event.

The Bay Area is similar to L.A. in that they reflect current conditions rather than advance warnings of closures or congestion. Weather warnings are also posted, with the signs dealing primarily with wind, fog, and wet pavement. Public service announcements are not displayed with two exceptions: notices for pending “spare the air days” when motorists are requested to car pool or use public transportation, and when the CHP requests that signs be posted reminding motorists that HOV lane restrictions will be enforced.

In Sacramento, signs are used to warn of pending closures as well as current traffic conditions and weather. For the most part there are no public service or informational messages displayed. One exception is signs warning of high fire danger.

CHANGES

Information is the lifeblood of the TMC - gathering (incident detection), analyzing (incident verification), and disseminating (notifying the driving public). When TMC personnel are asked what changes they would make if they could build a TMC from scratch, their first choice is almost always more CCTV cameras, followed by more CMSs. With cell phones, incident detection within minutes of occurrence is a given - little improvement is possible or even necessary. Time is lost waiting for verification, however, time that could be used to get a TMT rolling, CMSs and HARs turned on, and appropriate equipment to clear the incident on its way (while clearing the vehicles involved in a crash is a CHP task, the job of clearing debris and repairing damage to the roadway belongs to Caltrans). The CHP could also profit from more cameras. It take time to get the first unit on scene. With more cameras, the incident could be assessed from within the TMC and emergency equipment, HAZMAT teams, tow trucks, and additional CHP units could be dispatched as needed before the first unit even arrives.

One major problem voiced by personnel at all three TMCs is dealing with legacy equipment and systems. In Oakland, three types of software are needed to perform the required tasks. Old equipment is in constant need of repair. On any given day in L.A. and Oakland, 40 to 50 percent of the CCTV cameras are either without a picture or cannot be controlled from the TMC. In Sacramento the number is approximately 25-30 percent.

With the exception of Sacramento, the relationship between Caltrans and CHP personnel within the TMC is not a close one. This is not to say that it is bad, but simply that it is not positive. While the CAD system is an invaluable tool, a greater understanding and appreciation of the roles and capabilities of other parties within the TMC could enhance it.

ASSESSING THE ROLE OF ITS AND TMCS IN CONGESTION AND PRODUCTIVITY

There have been numerous claims made regarding the value of both ITS and TMCs. These claims include a reduction in congestion and an improvement in network or system productivity. In earlier work (Gillen and Haynes, 2000) the contribution of alternative ITS applications was investigated using total factor productivity (TFP) models. In that work we were interested in two different aspects of ITS in correctly measuring the benefits of ITS applications. First, do ITS applications affect productivity in the local economy as traditional investments in transportation infrastructure might? Second, is there a difference in contribution between different ITS applications to productivity; for example, between ramp meters and changeable message signs? What this research examines is the growth and integration of ITS applications and their impact of different performance measures. The performance measures chosen are congestion and an efficiency output indicator. Using congestion as a performance measure focuses upon the input side, does ITS allow the system to achieve an output level with fewer inputs or lower levels of externalities? Using VMT is an output oriented performance measure where we examine the ability of the system to produce more output with the same inputs, simply adding technology to combine and use these inputs more efficiently; for example, ramp meters provide integration between links on a network. In the work we distinguish automobiles and trucks in the sample to make a distinction between production side benefits and demand side benefits that would properly be quantified by consumer surplus measures.

California has 5 counties which dominate the implementation of ITS. These are Los Angeles, Orange, Riverside, San Diego and Santa Clara. When information from these counties is combined win a panel with that of other counties in California we end up with a good deal of variation in the data that should help us distinguish impacts if there are any. The econometric work is designed to examine three questions. First, does ITS improve the performance of the system as indicated by our two performance indicators? Second, are there differences between different ITS applications? Does performance improve more with ramp meters than with CMSs and how does this change over time if at all? This third question goes to the issue of what we term the ‘S’ curve effect. This is similar to a product cycle where an ITS application is introduced and initially may have a small impact on performance but as the system users integrate the new technology into their decision making we see an improvement in performance and then a subsequent tapering off of the performance gains. This S-curve is measured by a new technique that looks at regime changes. Essentially we treat the introduction of a new technology as causing disequilibrium in the system, the system components take time to get back into equilibrium. The correct measure of the benefits from the introduction of the new technology is the difference in the level of the performance measures between the two equilibrium positions.

PERFORMANCE MEASURES AND ITS APPLICATIONS

Before reporting on the statistical analysis it is useful to examine the behavior of the relationship between changes in our indicators, congestion and VMT and the ITS applications in each of the five primary ITS counties. These are contained in Figure 4 through Figure 39. In Figure 4 the VMT over the period 1964 through 1998 is graphed. They appear to have peaked in 1991 and dipped through the early years of the 90s when a mild recession hit California. Since 1995 VMT for both trucks and cars has been climbing. However, two important attributes of the data are evident, first, truck VMT has caught up to auto VMT. This is the result of a combination of circumstances including poor quality service on the rail system particularly with recent mergers, the shift to JIT production and manufacturing and the greater use of small delivery trucks with the geographic spreading of small firms. Second, the growth in auto VMT has not grown significantly since 1990, this despite a rapid increase in population and in vehicles.[3] The aggregate information indicates a period of steady growth up to the early 1980s, then rapid growth over the next decade, followed by slow growth until the late 19902.

Figure 5 illustrates the values of the levels of congestion for selected counties in California, using the congestion index developed by Boarnet et al. (1998).[4] Up to the early 1980s a number of counties have increasing levels of congestion, a period of 'turbulance' or disequilibrium from 1981 through to around 1987 and then a continuing downward trend. The downward trend eases and the index is relatively constant after 1992.

Figure 6 illustrates the growth in TMC components, ramp meters and CMSs over the period 1969 through 1998. CMSs were of little consequence until early to mid 1980s with small growth in numbers in the 1980s and rapid growth after 1992, until today when we have over 250 in place. Ramp meters have been with us for much longer and have a significantly different growth profile. There was slow growth until late 1970s, rapid growth in the early 80s, slow growth in the mid 80s and quite rapid growth in the late 1980s. A short period of slow growth in the early 90s was followed by very rapid growth in the remaining period.

The profiles are important in two respects. First, they provide sufficient variation over time that we should be able to observe some statistically significant relationship between the introduction of TMC components and the change in the performance measures. Second, and as it turns out, most importantly, it explains the pattern of change in the congestion indices. It also permits us to explore the issu eof what can be termed the 'S' curve effect which essentially refers to the rate at which a new ITS component affects the VMT, congestion and efficiency of the location and community in which it is located. The simple notion, explained in greater detail in the subsequent discussion in the analysis of the results, is any investment introduces a disequilibrium and it causes people to alter their behavior. Once they have adjusted, the system gets back into equilibrium. The new equilibrium represents either of two outcomes. The impact of the investment in adding capacity has been fully exploited or there has been a permanent increase in performance.[5]

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[3] It may also be a statistical artifact that results from an increasing proportion of miles being driven on non-state and local roads.

[4] Marion G. Boarnet, Eugene Jae Kim, Emily Parkany. *Measuring Traffic Congestion*, UCI-ITS-WP 98-6 0193-5860 ;

[5] This could, for example be represented by a downward shift in a congestion index or an upward shift in an efficiency index.

Figure 7 shows the growth in aggregate auto and truck VMT over the period of analysis. The pattern evident in Figure 4 is evident here as well bu the spread between truck and auto is clearer and, the shift from local and state roads to ‘other’ roads can explain the difference between the two figures. Truck VMT exceeds auto after 1981 and grows faster in the late 80s. As before this growth path may reflect the investment in roads, ITS and TMCs as the new technology raised the productivity and performance of the system.

Figure 8 and Figure 9 show the growth of ramp meters and CMSs by county. Referring back to Figure 5 the counties with the greater congestion were more likely to receive the ITS and TMC investments. This may create a problem in estimation, in that higher congestion leads to pressures to invest in new capacity or new technology and this reduces congestion,. Thus the investment is a function of the performance of the system rather than the performance of the system is a function of the investment. One is a supply response and the other a demand response.[6]

Figure 10 through Figure 39 provide the path of investment in either ramp meters or CMSs for each of the five ITS intensive counties in California. Ideally, employment of CMS and ramp meters should improve traffic flow and freeway efficiency, allowing for more traffic with less congestion. Productivity of the highway system, measured in Vehicle Miles of Traffic should increase as ITS elements are implemented. Conversely, upon implementation of ITS elements, the congestion index should fall as ramp meters and CMS cause better traffic flow.

For each of the counties, cross sectional charts were prepared for each of change in CMS and change in Ramp Meters against the changes in Auto VMT, Truck VMT and the Congestion Index. The charts for the VMTs consist of the years 1970 to 1997 while the charts for the Congestion Index are for 1977 to 1997.

Los Angeles is the largest county in California, in terms of population. As a result, there are more traffic and road miles than any other country. It is fitting that it employs the most ITS elements.

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[6] We handle this problem with a new technique whi9ch traces out the disequilibrium resulting from the introduction of ITS investments.

Figure
4

VMT per State and Local Miles of Roadway

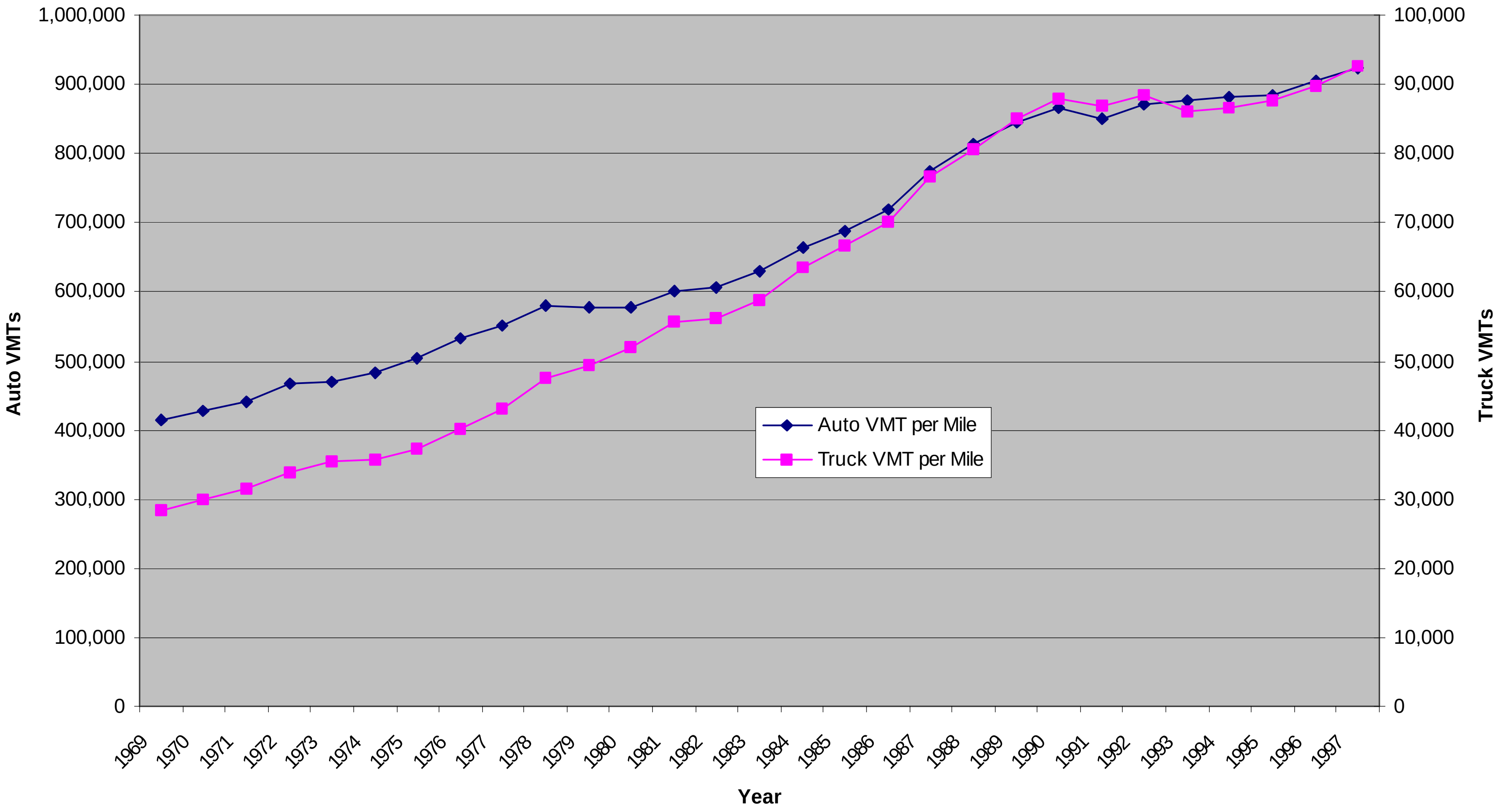
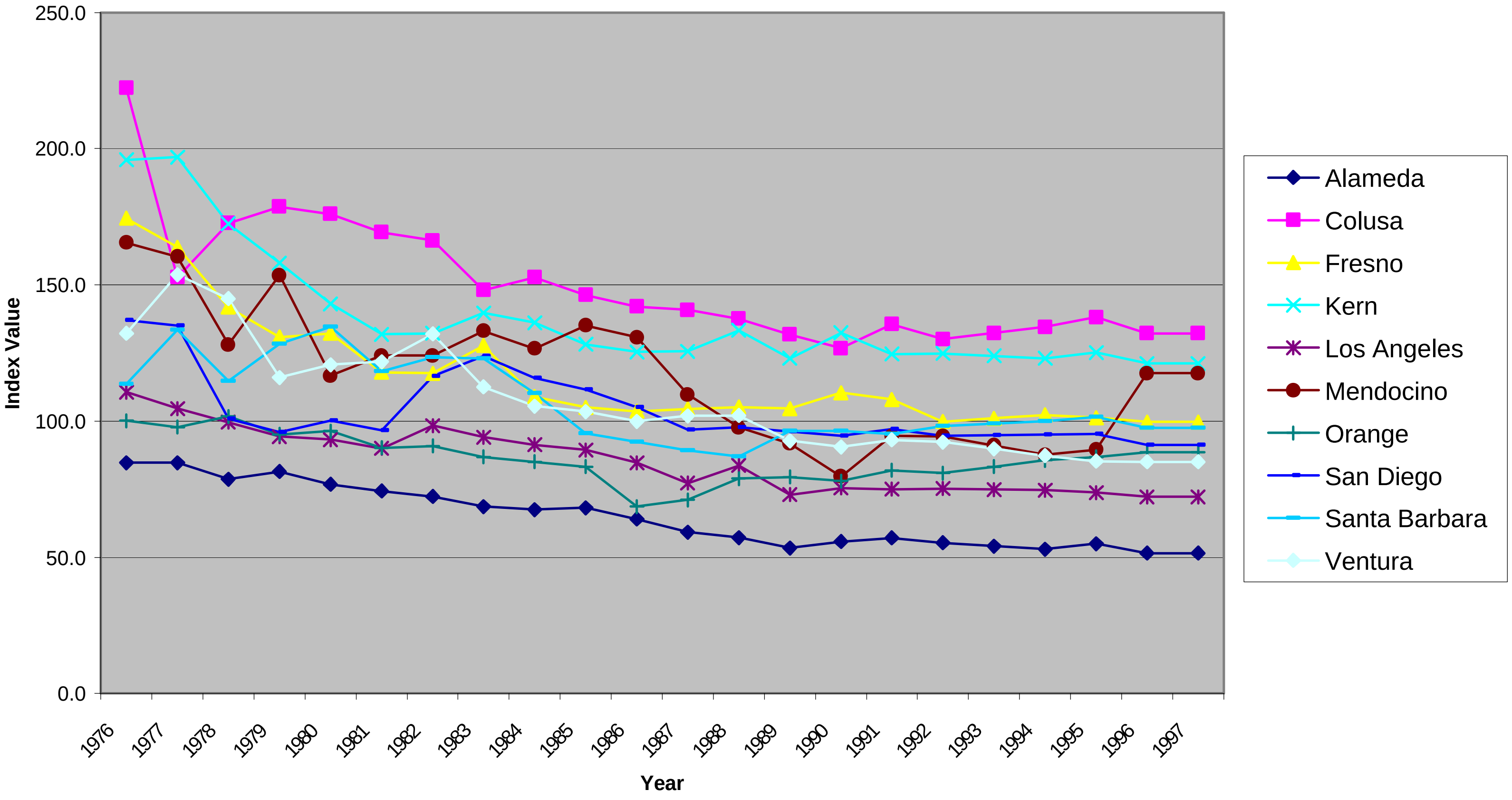
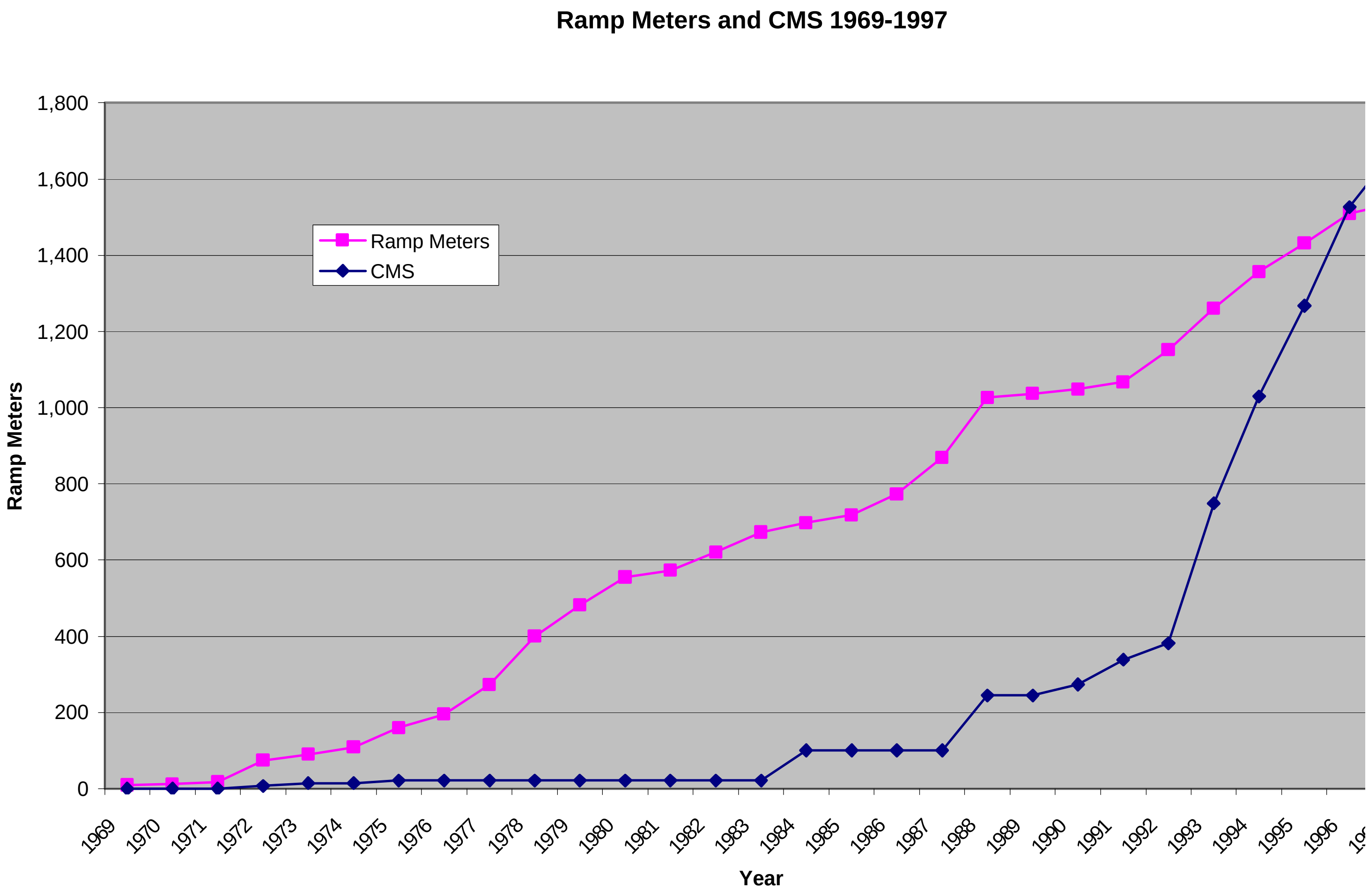


Figure 5



Congestion Indicies for Selected Counties 1976-1997

Figure 6



Ramp Meters and CMS 1969-1997
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Ramp Meters
Ramp Meters
CMS
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
Year

Figure 7

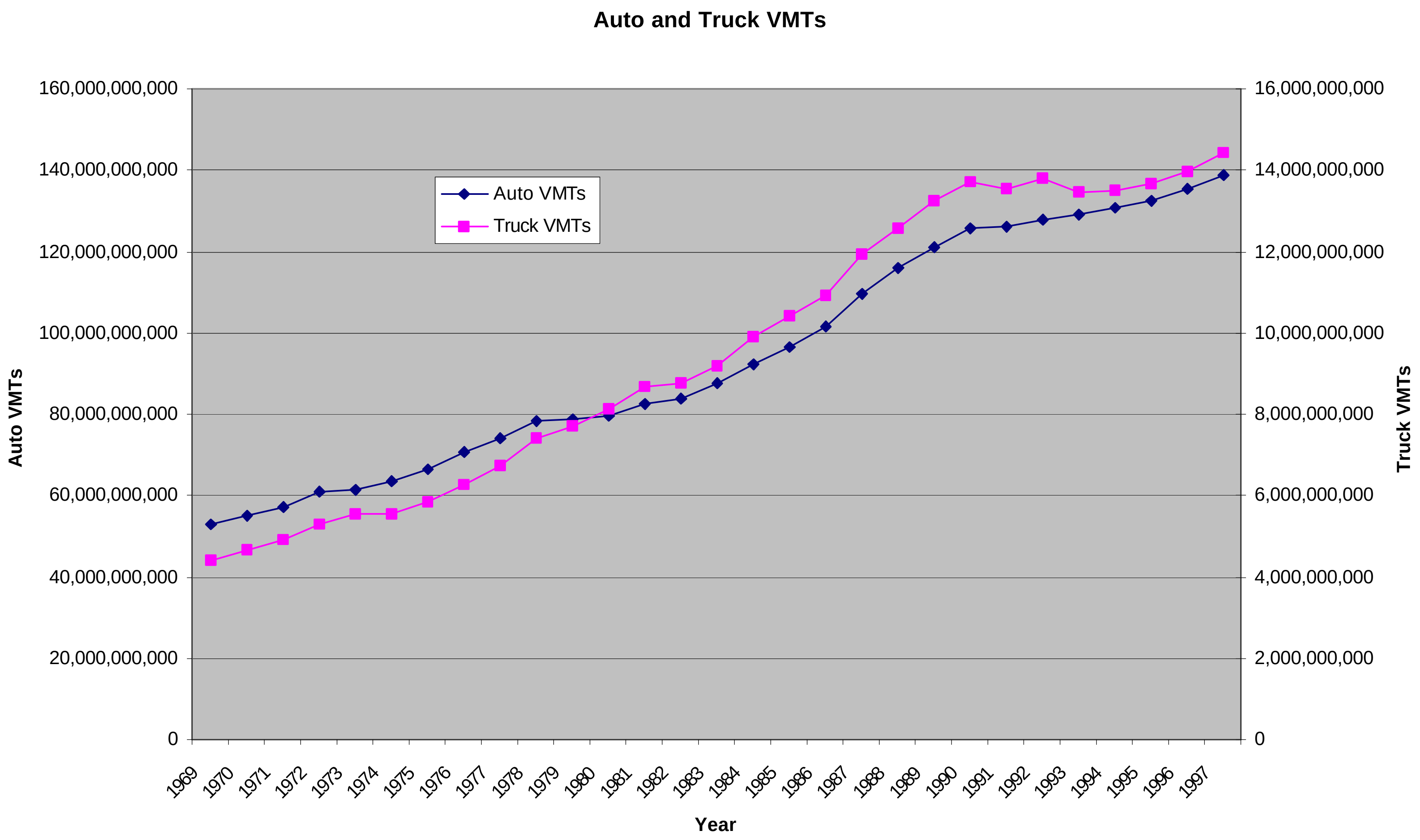
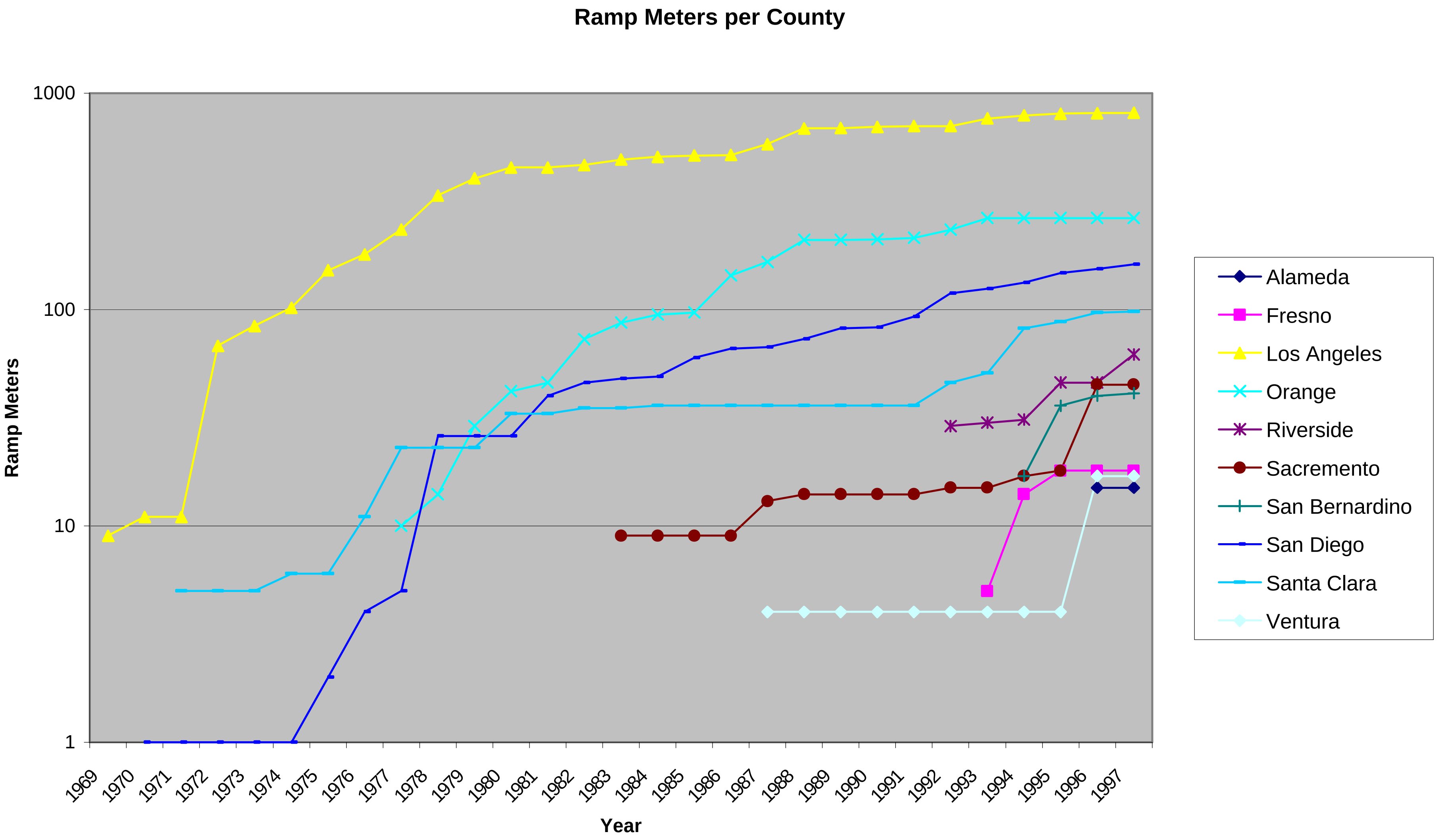
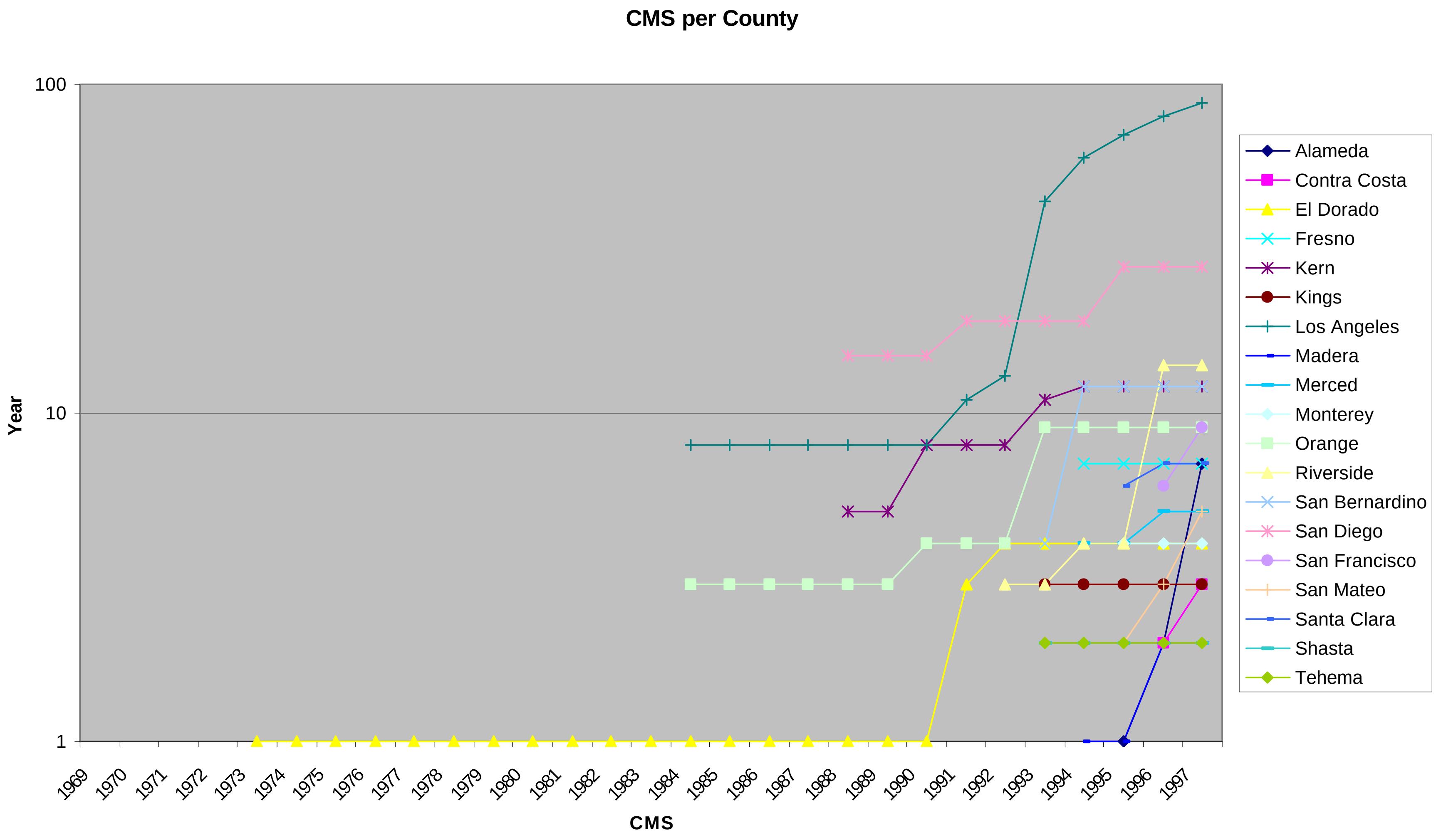

Auto and Truck VMTs
Auto VMTs
Truck VMTs
0
20,000,000,000
40,000,000,000
60,000,000,000
80,000,000,000
100,000,000,000
120,000,000,000
140,000,000,000
160,000,000,000
0
2,000,000,000
4,000,000,000
6,000,000,000
8,000,000,000
10,000,000,000
12,000,000,000
14,000,000,000
16,000,000,000
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
Year

Figure 8



Ramp Meters per County
1000
100
10
1
Ramp Meters
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
Year
Alameda
Fresno
Los Angeles
Orange
Riverside
Sacremento
San Bernardino
San Diego
Santa Clara
Ventura

Figure 9


CMS per County
Year
100
10
1
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
CMS
Alameda
Contra Costa
El Dorado
Fresno
Kern
Kings
Los Angeles
Madera
Merced
Monterey
Orange
Riverside
San Bernardino
San Diego
San Francisco
San Mateo
Santa Clara
Shasta
Tehema

For the charts mentioned above, the expected results hold. There is, however, a very slight relationship for Congestion and the VMTs. The data points are very dispersed around this relationship.

Orange County is adjacent to Los Angeles and also has a large population and the corresponding large amount of ITS. Again, the data follow the expected results with the same disperse data, but with a few exceptions. There appears to be a positive relationship between congestion and ramp meters, suggesting that the implementation of that element actually increase congestion. Furthermore, the VMT relationship with CMS implementation is negative, which suggests that highway productivity decreases with new installation of CMS. These results are counter-intuitive and should be examined with proper econometric analysis.

Of the five counties analyzed here, Riverside is the smallest in terms of ITS elements employed. As a result, data examination proves to be more difficult, with only three years in which there is an increase in CMS and four years with increases in Ramp Meters. Despite the minimal data points, the expected relationships appear to exist.

San Diego County has one of the largest populations in California, with corresponding high usage of ITS elements. Increases in Ramp Meters are far more frequent than that of CMS, and as a result, a better relationship for the meters can be seen in the VMT and congestion cross-sectional charts. Despite having few data points, the expected relationships still hold for the CMS comparisons

The last county analyzed is Santa Clara. Located slightly south of the Oakland-San Francisco area, Santa Clara has steadily increased its Ramp Meters while also implementing CMS at a slower pace. Indeed, there have only been two years in the data range where CMS have been increased, which causes difficult in the analysis. The Ramp Meter comparisons have data points that are so dispersed that it is difficult to see a relationship.

Los Angeles County

Figure 10

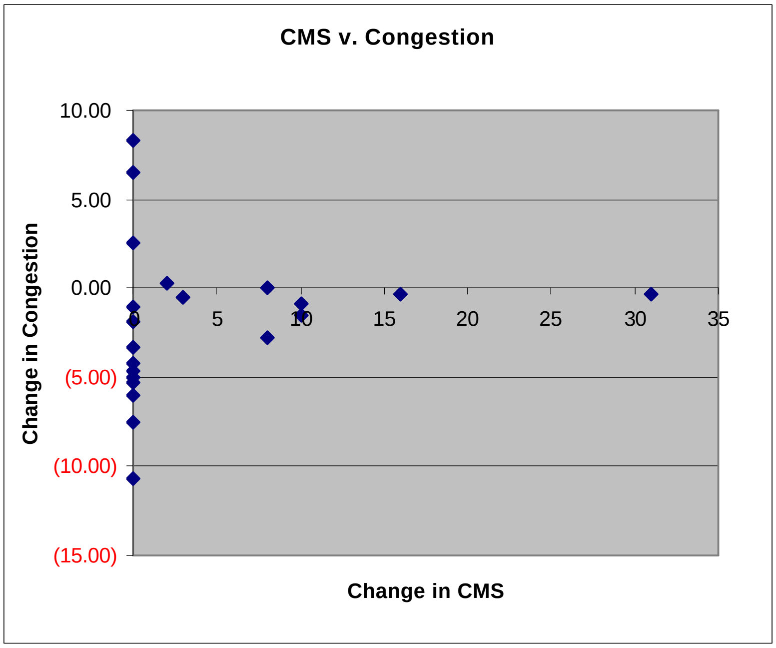


Figure 11

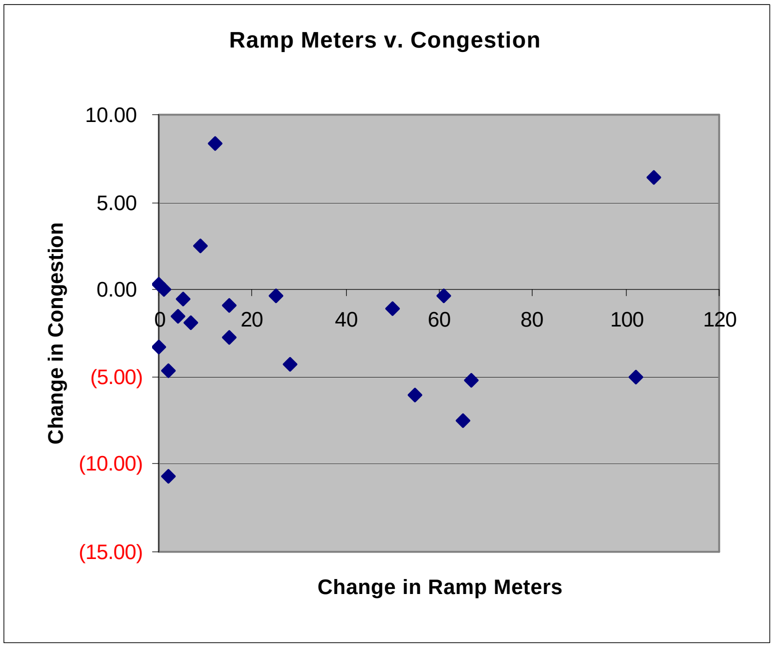


Figure 12

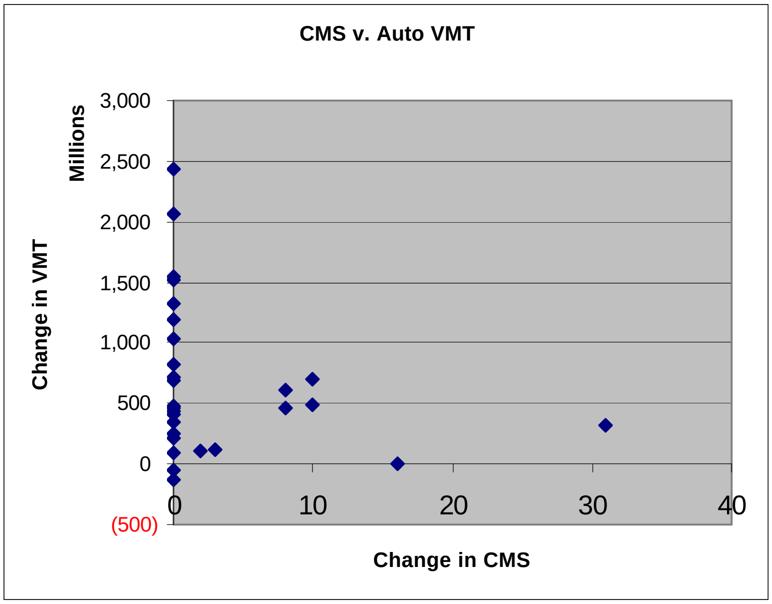


Figure 13

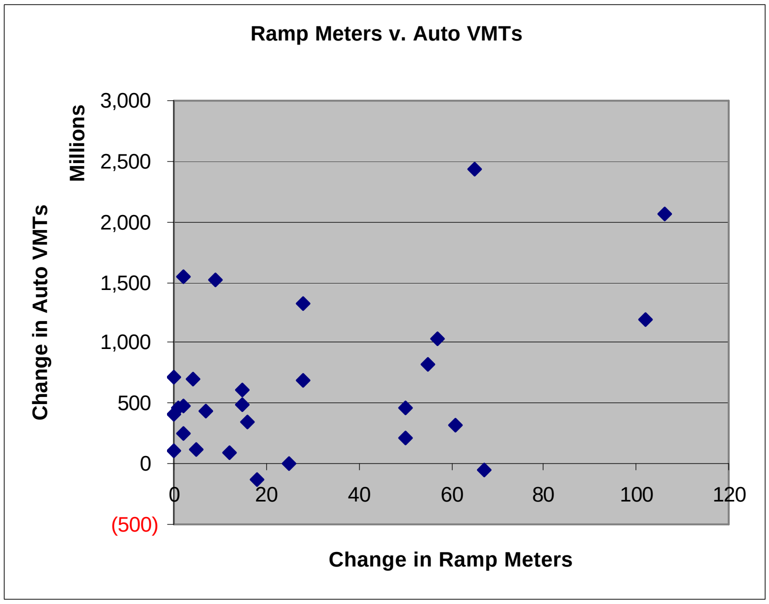


Figure 14

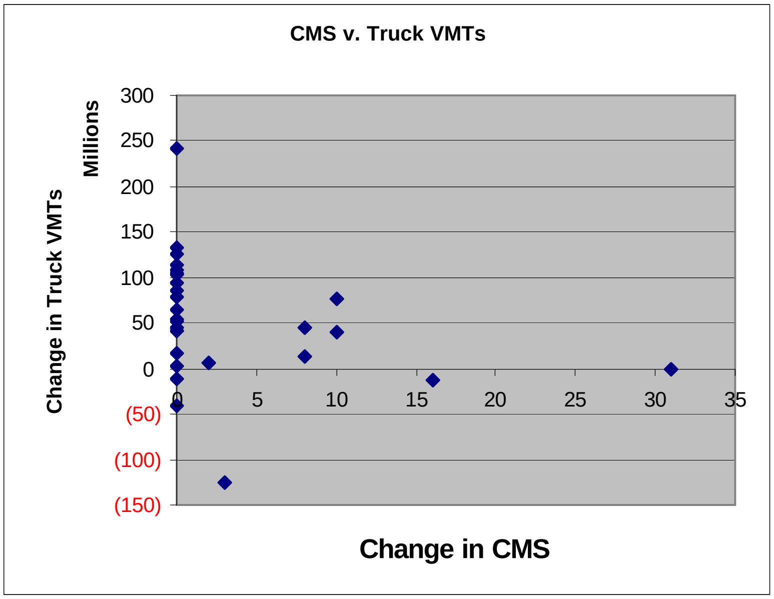
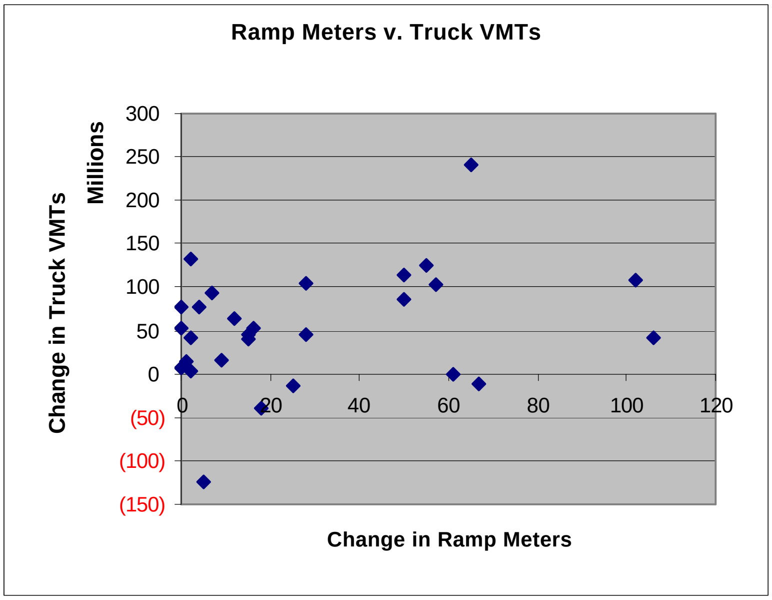


Figure 15



Orange County

Figure 16

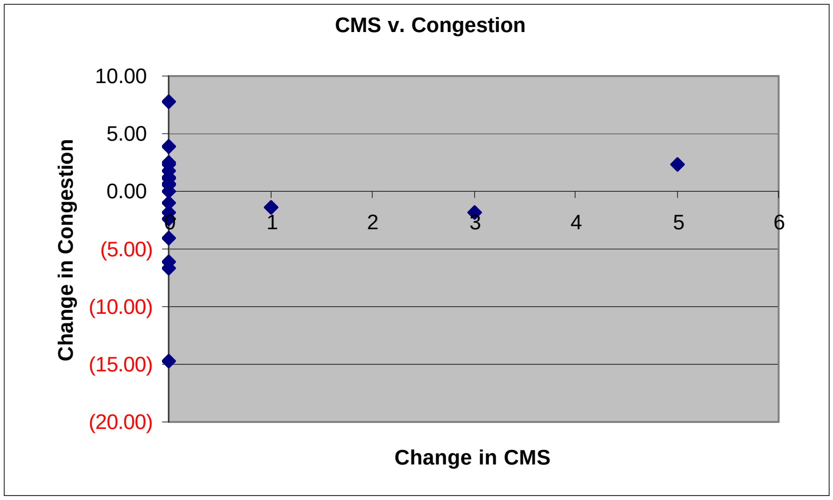


Figure 17

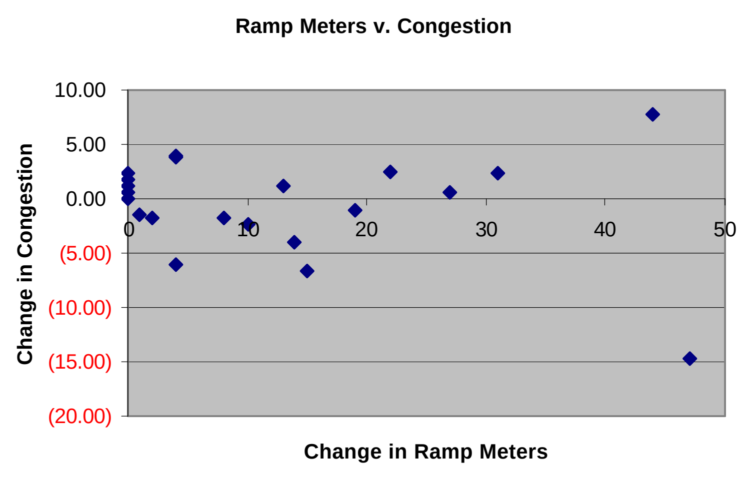


Figure 18

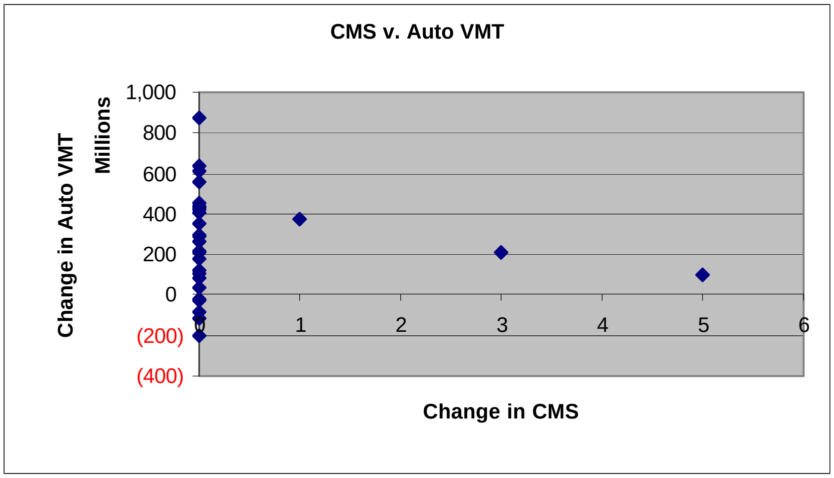


Figure 19

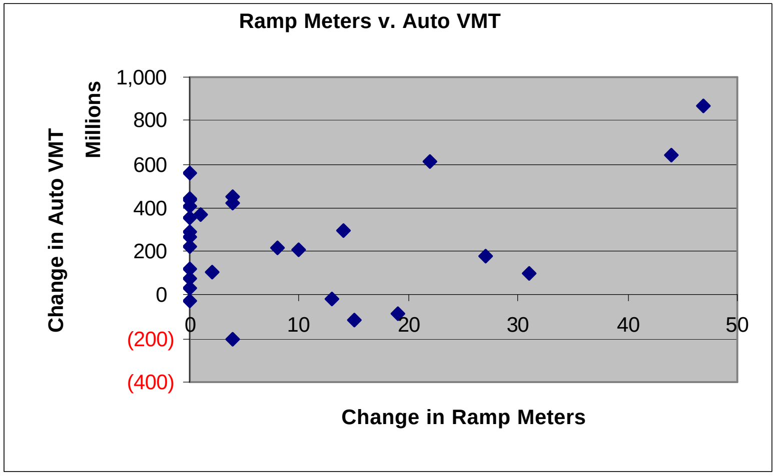


Figure 20

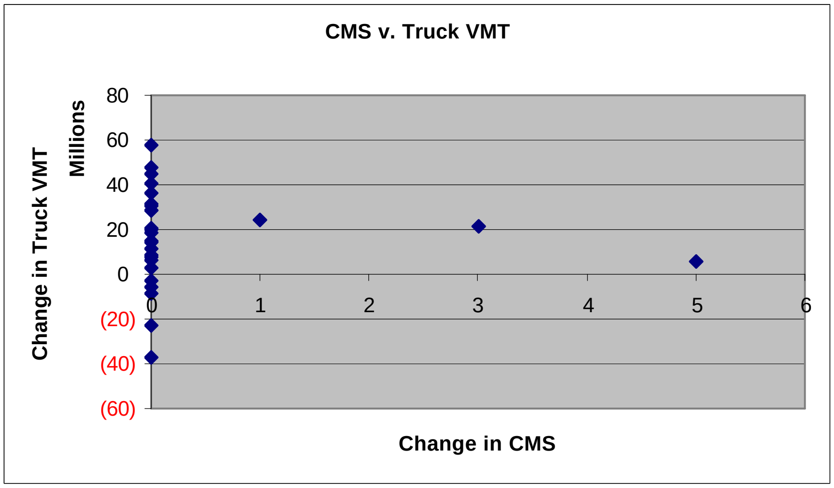
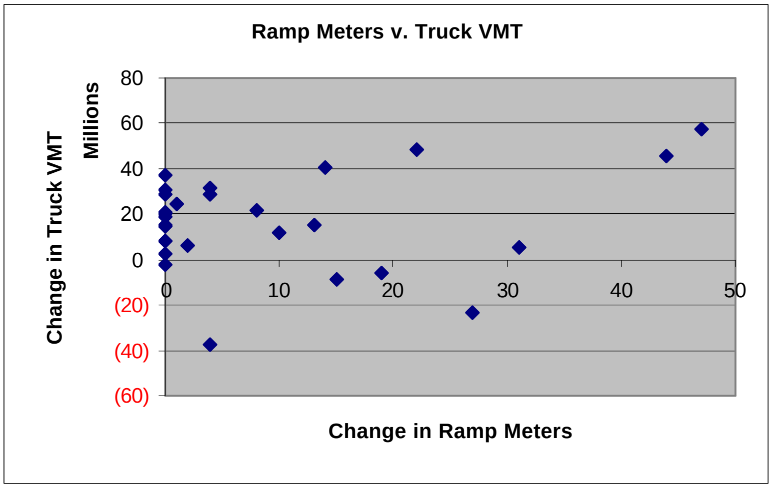


Figure 21



Riverside County

Figure 22

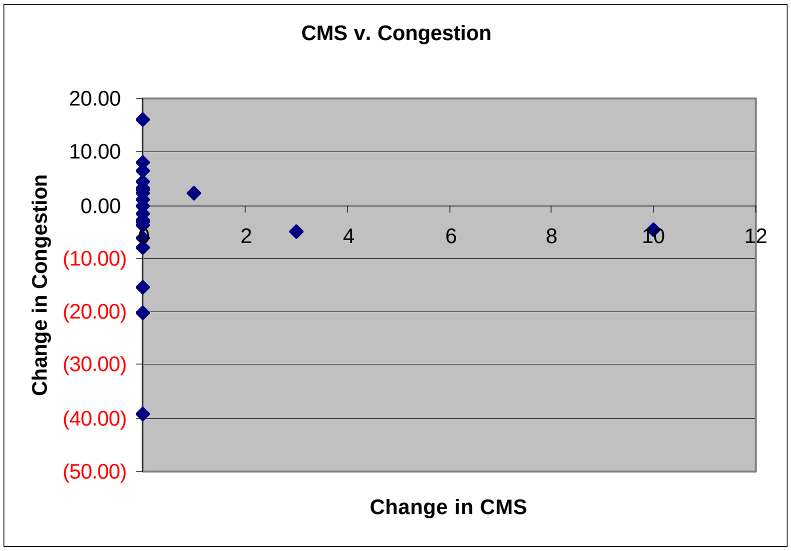


Figure 23

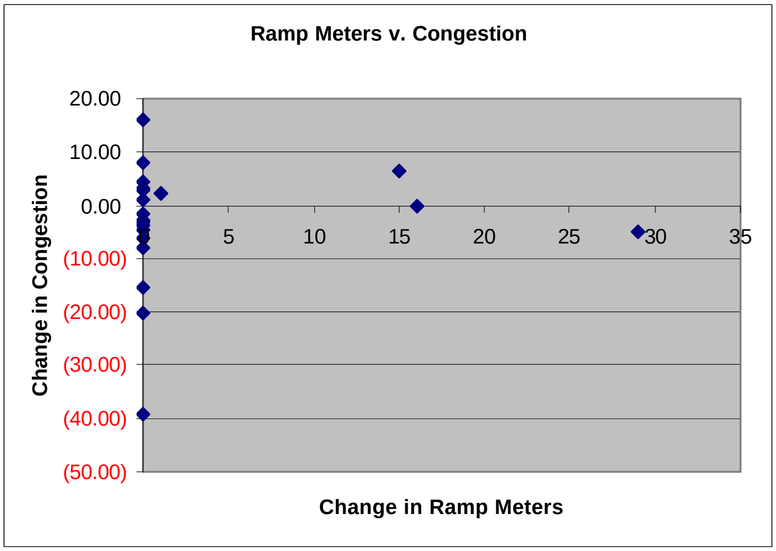


Figure 24

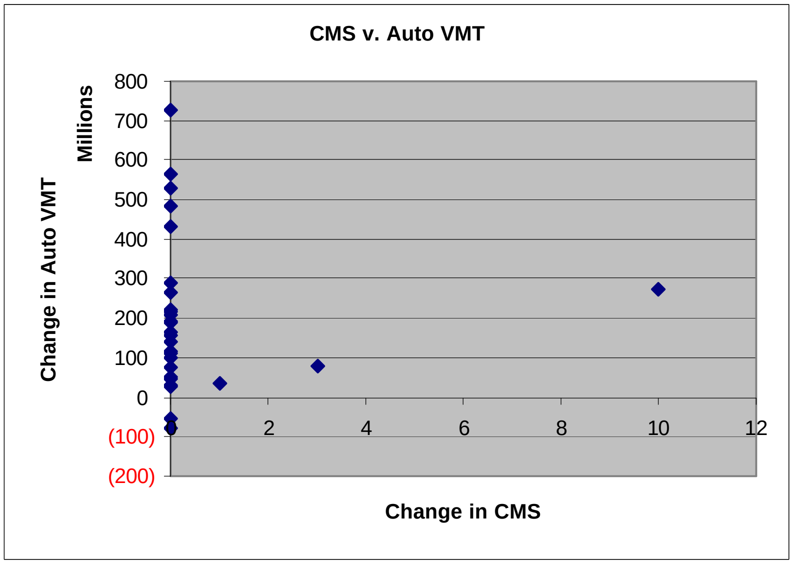


Figure 25

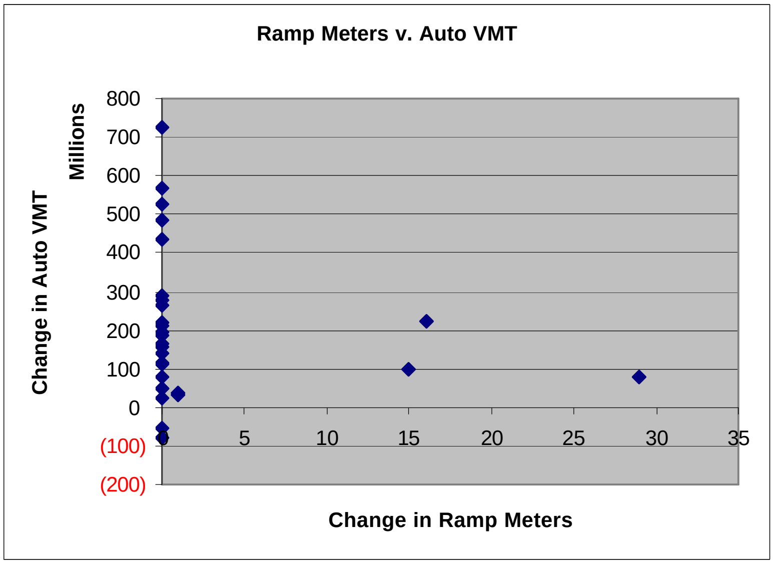


Figure 26

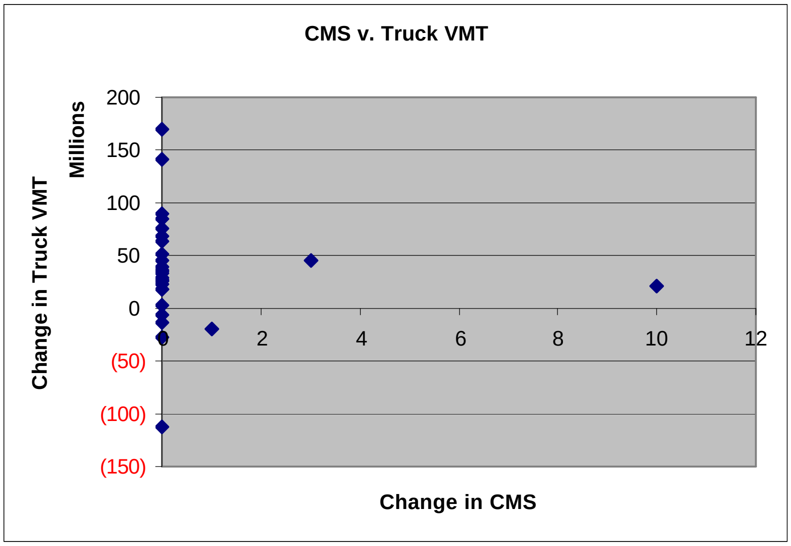
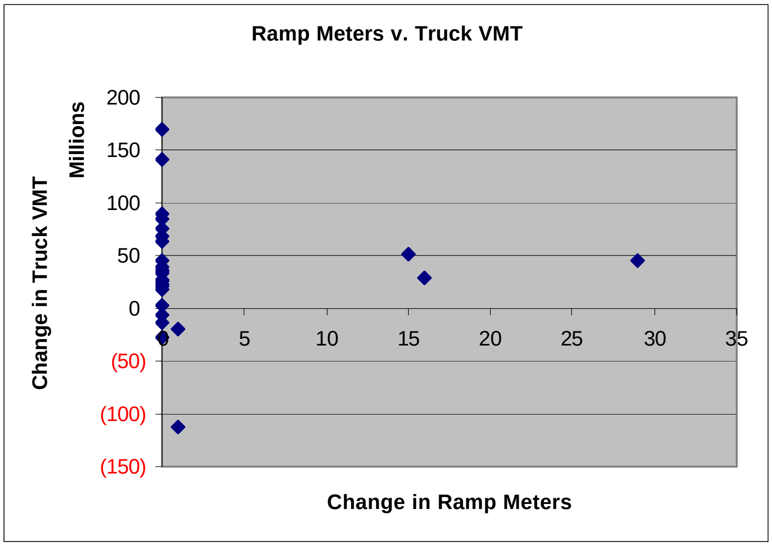


Figure 27



San Diego County

Figure 28

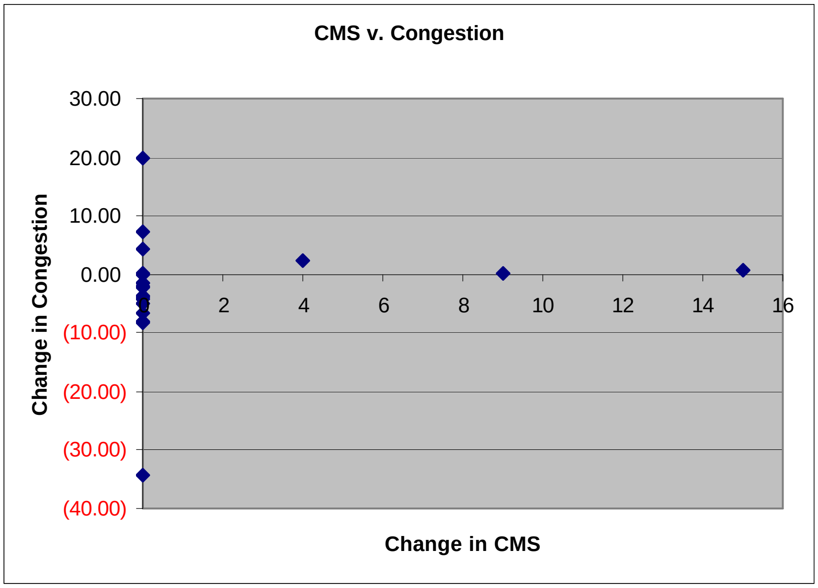


Figure 29

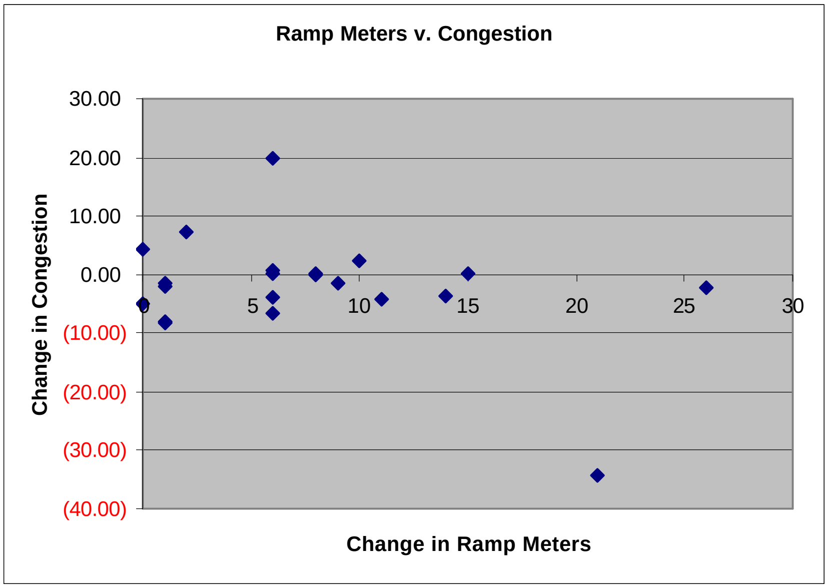


Figure 30

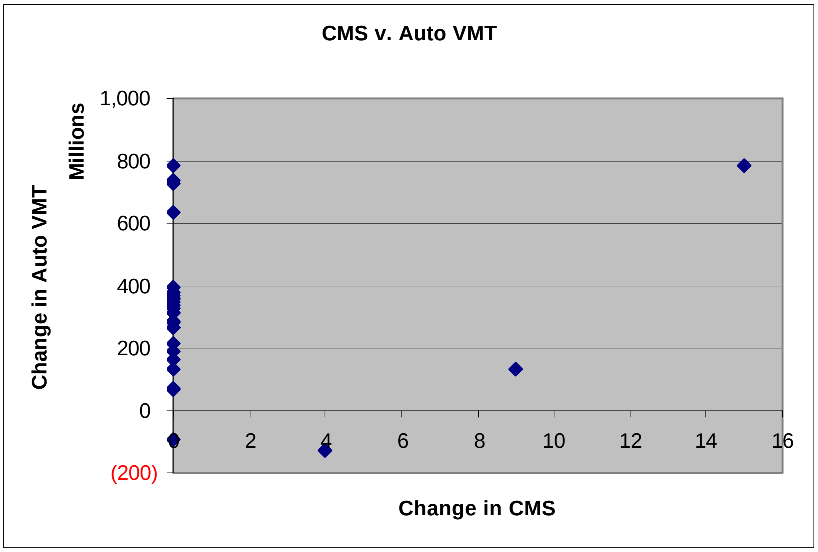


Figure 31

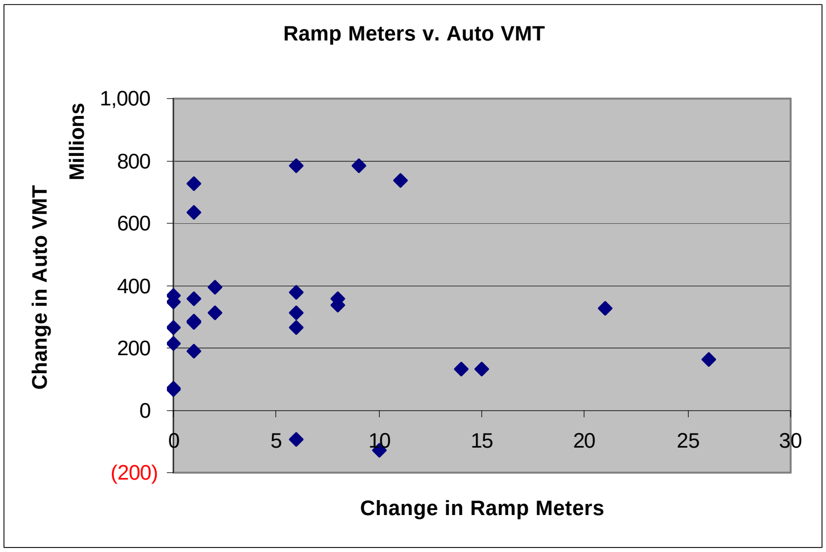


Figure 32

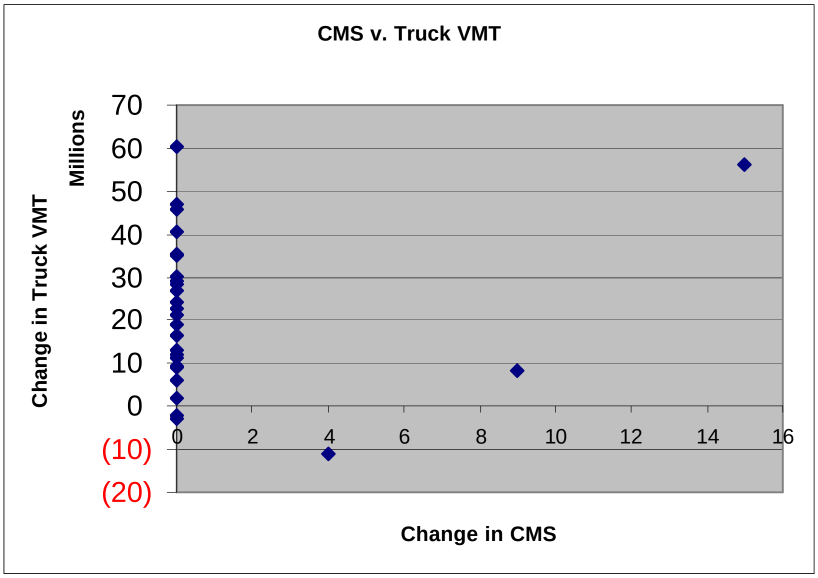


Figure 33

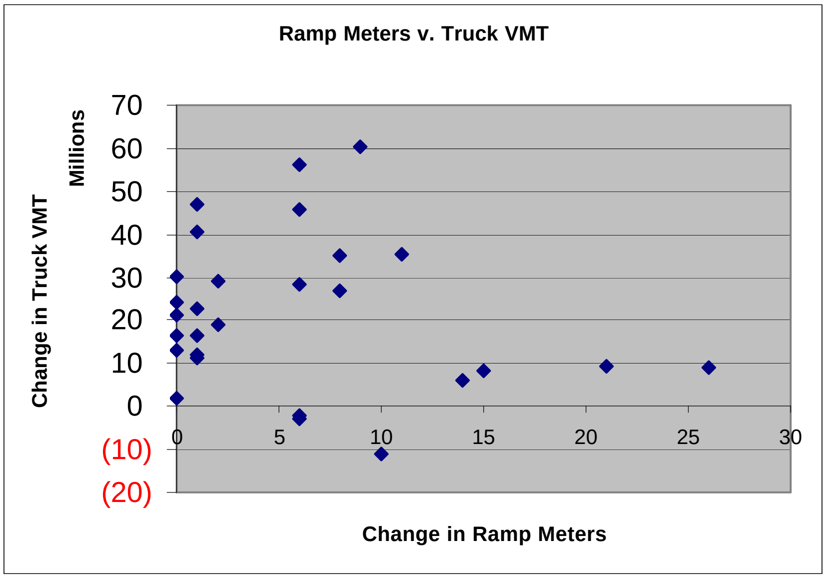


Figure 34

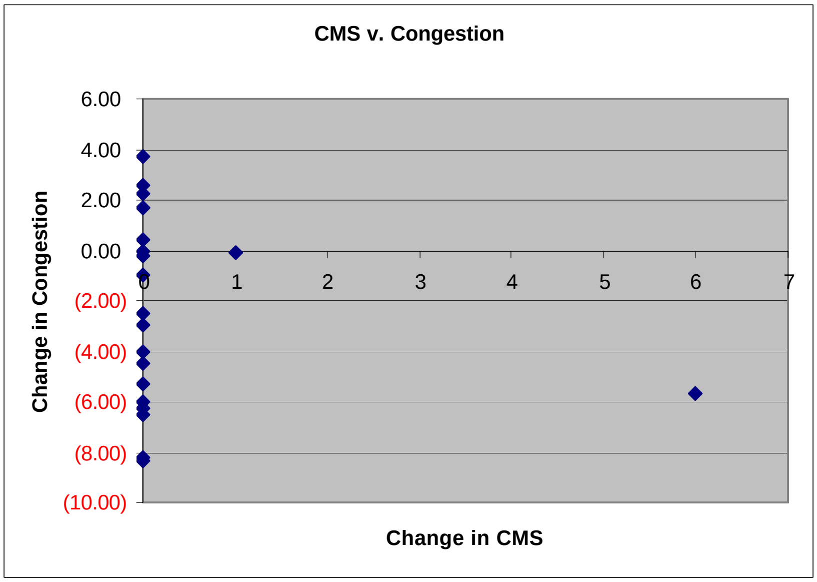


Figure 35

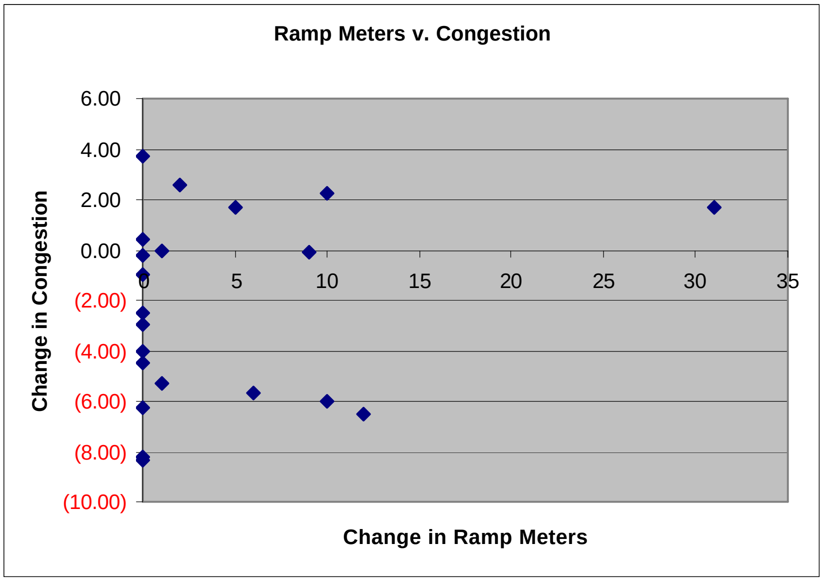


Figure 36

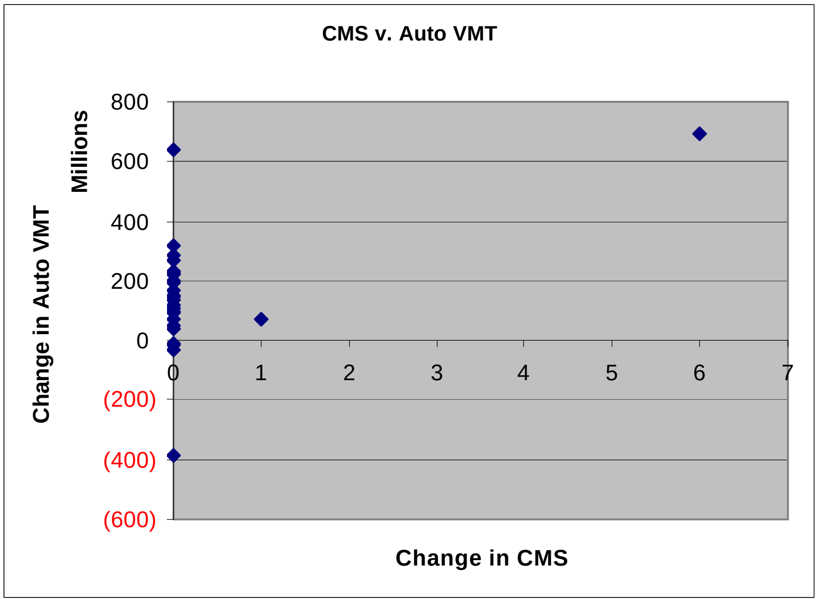


Figure 37

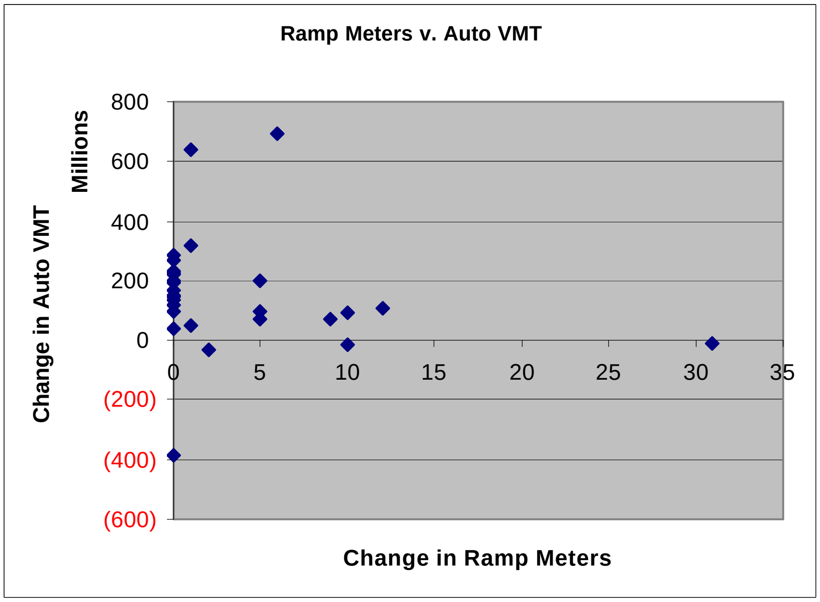


Figure 38

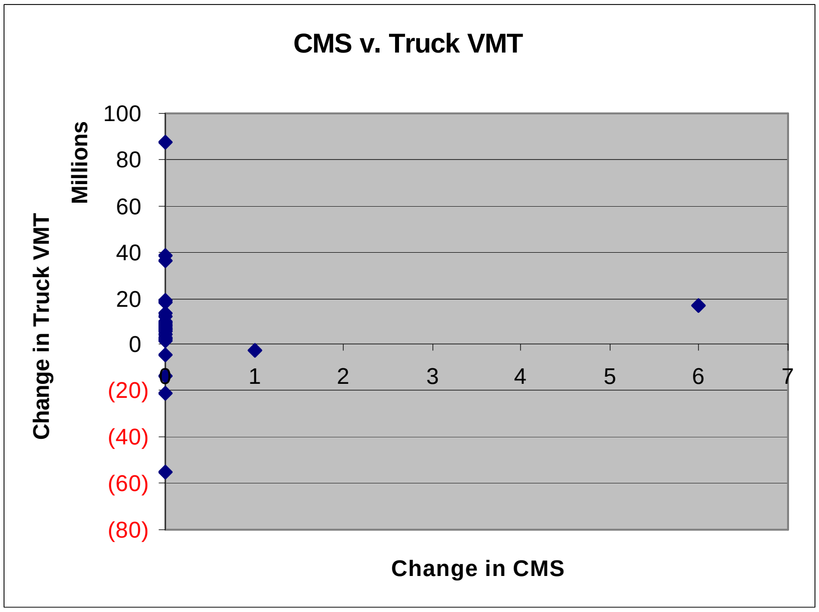
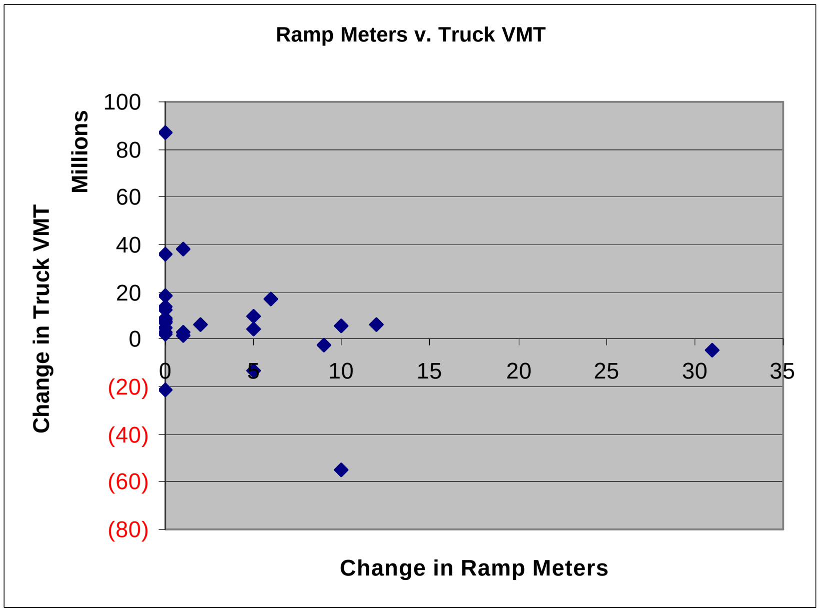


Figure 39



ANALYZING THE AFFECT OF TMCS ON PERFORMANCE

The analysis of the performance measures was undertaken in two steps. In the first case we estimated models that placed the number of ITS investments and TMCs as explanatory variables of changes in performance where performance was measured by increases in VMT and congestion. Two sets of models were estimated, level models that used the values of the variables and first differences that looked at the change in performance as a function of the change in explanatory variables and in particular changes in ITS and ramp meters and the subsequent development of TMCs. We report the difference model below.

In Table 7 the impact on the change in auto VMT of introducing ITS investments and TMCs is illustrated. Note that all variables are measured as first differences; changes from one year to the next. First, we can see that auto VMT has been increasing with time (TIME) and population (POPN). Income growth (INC) has a positive impact on auto VMT. The amount of expenditure on roadways (REXP) and miles of road (MILES) does not have a significant influence on auto VMT. Interestingly, increases in changeable message signs (CMS) and ramp meters (RM) do have a positive impact on auto VMT. The impact of ramp meters is double that of CMSs both are statistically significant but CMSs only marginally so (at the 10 percent level). The introduction of TMCs does not have a statistically significant impact on auto VMT. This is not surprising given the results of our case studies. In effect we found that despite the TMC organization, they cannot affect any real variables, they do not have the ability or processes in place to have an effect on decisions of users.

Table 7

Auto VMT as a Function of ITS Investments and TMCs

Dependent Variable: AMT
Method: Least Squares
Sample: 1 1624

Variable	Coefficient	Std. Error	t-Statistic
C	7661441	532513.00	14.39
POPN	3428.256	228.19	15.02
INC	37.94728	3.81	9.96
REXP	141.8731	232.43	0.61
CMS	3064573	2002500.00	1.53
RM	5858959	508153.30	11.53
MILES	31604.65	23211.83	1.36
TIME	1626809	445736.00	3.65
TMC	199577.9	482948.70	0.41

R-squared	0.588089	Mean dependent var	52863118
Adjusted R-squared	0.586049	S.D. dependent var	1.57E+08
Log likelihood	-32231.01	F-statistic	288.2189
Durbin-Watson stat	1.906238		

In Table 8 the results for changes in truck VMT are presented. The results are the reverse of what we found for auto; CMSs are more important in affecting changes in truck VMT than are ramp meters. This is intuitively appealing as ramp meters are of less value for truck sin affecting their productivity or performance. The relative values of the two ITS investments are about 3.5:1 whereas ramp meters outweighed CMSs for auto VMT by 1.9:1. As before the value of TMCs in affecting truck productivity or system productivity for truck VMT is not statistically significant.[7] One added feature distinguishing the truck VMT regression from the auto VMT regression is the explanatory power of the equation; the auto VMT had an R^2 of .58 while the truck VMT regression had an R^2 of only .27.

Table 8

Truck VMT as a Function of ITS Investments and TMCs

Dependent Variable: TMT
Method: Least Squares
Sample: 1 1623

Variable	Coefficient	Std. Error	t-Statistic
C	7128299	2893879	2.46
POPN	511.6231	40.0422	12.78
INC	1.423156	0.667088	2.13
REXP	-89.65204	40.31308	-2.22
CMS	1296227	381994.2	3.39
RM	362671.4	88140.96	4.11
MILES	3064.78	4085.395	0.75
TIME	863134.1	548379.6	1.57
TMC	-182846.4	139417.2	-1.31

R-squared	0.27718	Mean dependent var	6179954
Adjusted R-squared	0.273597	S.D. dependent var	20549949
Log likelihood	-29367.7	F-statistic	77.36511
Durbin-Watson stat	1.740101		

We also estimated equations that included dummy variables for all counties. The results changed very little and most country dummies were not significant. However the results from using dummies for those counties that have TMCs were more interesting. The results for changes in auto and truck VMT are presented in Table 9 and

On the other hand an inspection of the truck VMT change equations, Table 8 and Table 10, exhibits a somewhat different pattern from the auto equations. The relative importance of CMS compared to ramp meters has decreased to 2:1. The role of TMCs is still not statistically significant. If we scale the impact o fthe county dummies, as with the auto equation, there is a quite different pattern from the auto equation. Indexing relative to LA, Orange County is 1.1 or 10 % more growth than LA, while Riverside

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[7] It is also statistically insignificant.

is at 1.6 or 60 % more than LA, San Diego is 0.6 and Santa Clara at .1. The latter two results should not be surprising in areas with high knowledge based industries. Interpreting again as before the dummies are picking up truck VMT growth not attributable to the parameterized variables in the regression. Therefore, Orange County and Riverside have significant truck VMT growth not explained by ITS investments while San Diego and Santa Clara both have a close correspondence with ITS investments.

Table 10. The addition of the dummy variables allows us to distinguish impacts of ITS investments and the addition of TMC given that TMCs are present. In these cases the TMC variable is a time dummy as to when TMCs were introduced rather than indicating the presence of a TMC. The results differ from those found in the estimates without the dummy variables. In the auto VMT equation, comparing Table 7 and Table 9, the coefficient on the CMS variable has decreased while that on the RM variable has risen. This implies an even greater contribution of ramp meters to increased auto VMT and a lesser role for CMSs. The introduction of TMCs is still insignificant. One might interpret the estimates as measuring the incremental contribution to efficiency (measured by either auto or truck VMT changes, from each ITS investment given the presence of the others. This would therefore imply that for auto VMT growth the most important contributor to network efficiency (as measured by auto VMT) are ramp meters. CMSs make a smaller contribution but the introduction of TMCs is not of consequence. The dummy variables pick up the differences between the TMC counties. Indexing all county dummies relative to Los Angeles (LA) shows Orange County (ORG) has auto VMT growth of 70% of LA, Riverside (RIV) has 10%, San Diego (1%) and Santa Clara (SCL) 30%. The interpretation would be, the dummies are picking up the growth in auto VMT not accounted for by the variables included in the regression. Therefore, ITS investments in improving efficiency of the network is quite high in San Diego and Riverside and to a reasonable degree in Santa Clara.

Table 9

Auto VMT as a Function of ITS Investments and TMCs (with county dummies)

Dependent Variable: AMT
Sample: 1 1623

Variable	Coefficient	Std. Error	t-Statistic
C	25434984	16577073	1.53
POPN	3555.198	255.8213	13.90
INC	47.86032	4.601118	10.40
REXP	159.1372	230.6792	0.69
CMS	1653829	1163656	1.42
RM	6696576	539026.9	12.42
MILES	21235.32	23438.84	0.91
TIME	1473322	1017232	1.45
TMC	458294.7	619735.5	0.74
LA	-1.40E+08	36424637	-3.84
ORG	-96187877	22422588	-4.29
RIV	12025620	20427580	0.59
SD	1575619	22210648	0.07
SCL	-40112572	20348284	-1.97
R-squared	0.596791	Mean dependent var	52901510
Adjusted R-squared	0.593533	S.D. dependent var	1.57E+08
Log likelihood	-32194.26	F-statistic	183.1911
Durbin-Watson stat	1.907505		

On the other hand an inspection of the truck VMT change equations, Table 8 and Table 10, exhibits a somewhat different pattern from the auto equations. The relative importance of CMS compared to ramp meters has decreased to 2:1. The role of TMCs is still not statistically significant. If we scale the impact o fthe county dummies, as with the auto equation, there is a quite different pattern from the auto equation. Indexing relative to LA, Orange County is 1.1 or 10 % more growth than LA, while Riverside is at 1.6 or 60 % more than LA, San Diego is 0.6 and Santa Clara at .1. The latter two results should not be surprising in areas with high knowledge based industries. Interpreting again as before the dummies are picking up truck VMT growth not attributable to the parameterized variables in the regression. Therefore, Orange County and Riverside have significant truck VMT growth not explained by ITS investments while San Diego and Santa Clara both have a close correspondence with ITS investments.[8]

Table 10

Truck VMT as a Function of ITS Investments and TMCs (with county dummies)

Dependent Variable: TMT
Sample: 1 1623
Included observations: 1623

Variable	Coefficient	Std. Error	t-Statistic
C	7263308	2846862	2.55
POPN	551.1644	43.93344	12.55
INC	3.287864	0.790173	4.16
REXP	-91.22571	39.61566	-2.30
CMS	1063452	388748.7	2.74
RM	486678	92569.73	5.26
MILES	4150.34	4025.266	1.03
TIME	786199.2	540489.6	1.45
TMC	176147	116430.2	1.51
LA	-20739634	6255381	-3.32
ORG	-21976749	3850741	-5.71
RIV	11198730	3508128	3.19
SD	-15078156	3814343	-3.95
SCL	-12292474	3494511	-3.52

R-squared	0.305857	Mean dependent var	6179954
Adjusted R-sq	0.300249	S.D. dependent var	20549949
Log likelihood	-29334.85	F-statistic	54.53593

The next set of equations focuses on the role ITS investments and particularly TMCs affect congestion. The former results were concerned with the impact on efficiency as measured by the growth in VMT.

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[8] Clearly the industrial makeup of the county would explain a good deal of the difference but it still raises the question whether it is cause or effect.

The same types of equations were estimated as above but with the dependent variable the congestion index as developed by Boarnet et al. (1998). We report the results with the dummy variables for the counties with TMCs in Table 11. The congestion indexes were presented in Figure 10 through Figure 39. Those figures show that the relationship is somewhat weak between ITS investments and changes in the congestion index. However, the statistical results although somewhat weak illustrate that controlling for county differences, ramp meters and CMSs reduce congestion, as measured by the index. Ramp meters appear to be 4 times as effective as CMSs. TMCs as before were not statistically significant in affecting congestion. The R^2 was also not particularly strong. Overall the model does not seem to have a lot of explanatory power in sorting out the differences in congestion among counties or what the underlying contribution is of ITS relative to investments. But it is evident that among conventional congestion relief measures maintaining infrastructure (roads) is more effective than expanding capacity. It also appears that ramp meters and CMSs, indicators of improved network management are more effective in reducing congestion than are expanding the network.

Table 11

Change in the Congestion Index with ITS and TMC

Dependent Variable: CONGEST
Sample: 1 1222

Variable	Coefficient	Std. Error	t-Statistic
C	-17.52118	3.523597	-4.97
POPN	-0.000062	0.000049	-1.27
INC	0.000002	0.000001	1.87
REXP	0.000070	0.000041	1.71
RM	0.040342	0.021065	1.92
CMS	0.015404	0.009701	1.59
MILES	0.00362	0.004049	0.89
TIME	2.213286	0.631837	3.50
TMC	0.471789	0.434035	1.09
LA	-0.627865	0.279262	-2.25
ORG	1.473767	1.095059	1.35
RIV	0.507447	4.099707	0.12
SD	0.792492	4.526782	0.18
SCL	-0.004538	0.002696	-1.68
R-squared	0.27248	Mean dependent var	-2.45497
Adjusted R-squared	0.006672	S.D. dependent var	16.89383
Log likelihood	-5177.343	F-statistic	1.630895
Durbin-Watson stat	2.294566		

SORTING OUT REGIME CHANGES

The empirical results described above led us to raise some questions, specifically, are we observing a shift in behavior as ITS investments are made and does the system take time to get back into equilibrium once an investment is made. The failure to observe strong statistical results, reported above, may be because any investment in capacity represents a regime change, this leads users to adjust their behavior and if this takes place at a slower pace, it may be some time before the full impact of the ITS investment takes place.

Regime changes are generally modeled as a dummy variable in a time series model. However, this requires one know when the impact of the change of interest took place was actually felt in the market. In some case there may be a lag of some period before a shift in behavior is observed. It may also be the case that there are several breaks as the system moves from equilibrium to disequilibrium and back into equilibrium again.

THE BAI-PERRON STOCHASTIC MULTIPLE BREAK MODEL

In this paper we apply the methodology due to Bai and Perron (1998, 2002, henceforth, BP). The BP methodology considers the following multiple structural break model, with *m* breaks (*m*+1 regimes)

$$(1)\qquad \begin{array}{l} y_t = x_t'b + z_t'd_1 + u_t\,,\; t = 1,\ldots,T_1\,, \\ y_t = x_t'b + z_t'd_2 + u_t\,,\; t = T_1+1,\ldots T_2\,, \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ y_t = x_t'b + z_t'd_{m+1} + u_t\,,\; t = T_m+1,\ldots T \end{array}$$

Where y_t is the observed dependant variable at time *t*; x_t is *p*x1, with associated coefficient vector b , which is assumed to be constant over the entire sample T; z_t is *q*x1, with associated coefficient vector d_j $(j = 1,\ldots,m+1)$; and u_t is the disturbance term with the usual assumed properties. The break points ($T_1,\ldots,T_m$) are treated as unknown, and are estimated together with the unknown coefficients when T observations are available. The BP methodology is to find the estimated break points ($\hat{T}_1,\ldots,\hat{T}_m$) such that

$$(2)\qquad (\hat{T}_1,\ldots,\hat{T}_m) = arg\ min_{T_1,\ldots T_m}\ S_T(T_1,\ldots,T_m)$$

Where $S_T(T_1,\ldots,T_m)$ is the sum of squared residuals. The minimization takes place over all possible partitions, so that the break points are global minimizers. BP use an efficient algorithm based on dynamic programming techniques.[9] In the terminology of BP, equation (1) represents a partial structural change model, in the sense that b does not change, and is effectively estimated over the entire sample, given the optimal partition. For some applications, *p*=0, and this is called a pure structural change model.

The BP methodology can be compared to an intervention analysis methodology, which also allows for a formal test of a change in the mean of a time series. Consider the simplest intervention model.

$$(3)\qquad y_t = a_0 + a_1 y_{t-1} + c_0 z_t + e_t$$

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[9] Details can be found in Bai and Perron (2002).

Here the variable z_t is the intervention variable. It is simply a dummy variable that takes a value 0 prior to a known event and 1 after the event. This is a form of equation (1), where $x_t = y_{t-1}$ and z_t from equation (1) includes the intercept, a_0. However, the major difference between equation (1) and equation (3) is that the latter must specify the break date a-priori, while in equation (1) the break(s) are determined *endogenously*.

Of course, the intervention model in equation (3) could be generalized to become

$$(4) \qquad y_t = a_0 + A(L)y_{t-1} + C(L)z_t + B(L)e_t$$

Where A(L), B(L) and C(L) are polynomials in the lag operator. In this case z_t is not constrained to lie on a particular deterministic path. Again, the problem with this specification is that z_t must be specified a-priori.

In the case of a change in strategy, policy or network, it is not known with certainty when the change will have an effect, or if there will be more than one effect, at different points in time. The BP methodology used allows the effects of the change in legislation to be endogenously determined by the data, within the framework of the model. This literature, like that of intervention analysis, grew out of the original literature on structural breaks and dummy variables, due to Chow (1960). In response to the large explosion of testing designed to search for the size of the autoregressive parameter in a time series (essentially searching for unit roots) in the 1980s and 1990s.[10]

Here we are interested in structural changes in the mean of three series: congestion indices (C_t); ramp meters investments, (R_t), and CMS investments (CMS_t). For each variable, we test for stochastic structural breaks using the following specification:

$$(3) \qquad y_t = d_j z_t + u_t$$

where the variable y_t = Ct, R_t, or CMS_t. Thus, in the BP terminology, this is a pure structural change model, where *p*=0, and $z_t = 1 \forall_t$.[11]

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[10] Perron (1987) wrote a series of papers showing that identification of a structural break in a time series often lead to the conclusion that the series could not be said to have a unit root, or simply that the size of the autoregressive parameter was overstated without considering structural breaks. Perron was criticized for imposing any break date a-priori, and the result was a series of papers due to Banerjee, Lumsdaine and Stock (1992), Zivot and Andrews (1992) and Perron (1997). The BP technique is the latest in this series.

[11] The model of pure structural change as a break in the mean of a series has been applied in several papers. Hamilton (1988) uses a two state Markov model and finds a change in the regime of the mean of the U.S. nominal interest rate between late 1979 and late 1982; Garcia and Perron (1996) use a similar methodology to analyze the question of whether there are breaks in the mean of the U.S. real interest rate series for the U.S. over the period 1961 to 1986. Caporale and Grier (2000) use the BP methodology to uncover breaks in the mean of the U.S. real interest rate and shifts in political regime; Atkins (2002) uses the BP methodology to uncover breaks in the mean of the Canadian and U.S. nominal interest rates and inflation rates; Bai and Perron (2002) apply the BP methodology to the U.S. real interest rate and the U.K. Phillips curve..

We utilize the following procedure suggested in Bai and Perron (2002). First, we calculate the UDMAX and WDMAX statistics. These are double maximum tests, where the null hypothesis of no structural breaks is tested against the alternative of an unknown number of breaks. These tests are used to determine if at least one structural break is present. In addition, the SupF(0|*l*) is a series of Wald tests for the hypothesis of 0 breaks vs. *l* breaks. If these tests show evidence of at least one structural break, then the number of breaks can be determined by the Bayesian Information Criteria (BIC), a SupF(*l*+1|*l*) test and sequential application of the SupF(*l*+1|*l*) test. These three tests will not necessarily give the same answer for the number of breaks or the break dates. In the results presented below, these tests are consistent in estimating the number of breaks, but there is some minor variation in estimating the break dates. In these latter cases we follow BP(2002), who recommend relying on the sequential test results.

The data series we are examining are reflected in Figure 7, Figure 8 and Figure 9 as well as the congestion index measured for each county.

TESTING FOR THE EXISTENCE OF BREAKS- THE 'S' CURVE EFFECT

On Table 12 we present the results of the UDMAX, WDMAX, and SupF(0|*l*) tests, for each of the three variables. The results in Table 12 are consistent with at least one break in each series. Therefore, we proceed to test for the number of breaks, and to identify the break dates. These results are presented on Table 2

Table 12

Structural Break Tests

	C_t	R_t	CMS_t
Udmax	59.24	68.38	25.50
Wdmax	59.24	73.22	27.63
SupF(0|1)	59.24	42.01	25.50
SupF(0|2)	47.04	68.38	16.80
SupF(0|3)	34.96	54.31	20.77

Note: For the Udmax and Wdmax, the null hypothesis is 0 breaks against the alternative hypothesis of an unspecified number of breaks; for the SupF(0|*l*), the null hypothesis is 0 breaks against the alternative of *l* breaks. All test statistics reject the null of 0 breaks at at least 95%.

Table 13

Estimated Breaks

	C_t	R_t	CMS_t
SupF(2|1)	20.31	29.24	17.23
SupF(3|2)	22.67	23.39	17.23
BIC	1	1	2
Sequential Procedure	1	1	2
$\hat{d}_1$	309.50	100,347	
s.e.	(215.06)	(89,381.61)	
$\hat{d}_2$	360.75	115,376	3.09
s.e	(212.48)	(932637.42)	(2.47)
$\hat{d}_3$	283.14	91,812	2.84
s.e	(344.61)	(66,583.46)	(1.32)
$\hat{d}_4$	258.65	99,528	2.60
s.e.	(201.50)	(71,242.66)	(2.46)

In Table 13, the SupF(*l*+1|*l*) tests reject for *l*=1,2 for C_t and R_t, suggesting although there is some evidence breaks in each of these series they are not statistically significant. This is consistent with the number of breaks chosen by the BIC and sequential tests but it also shows that the turning gpoints are not clear and cannot be distinguished from other events. For the CMS_t the SupF(*l*+1|*l*) appears to reject for *l*=1. However, the break chosen for *l*=2 is identical to that chosen for *l*=1. Again we are faced with the problem of no statistical significance. Although there are points of obvious change, turning points, we are trying to relate these to changes in congestion, as we did with ramp meter investment. There is simply too little data to test the role of TMCs using this framework. Given our case studies and previous empirical results, it is highly unlikely we would have found any significance.

SUMMARY AND CONCLUSIONS

Our purpose in this research was to better understand the role and impact of TMCs. We used three techniques. First, our case studies of three different TMCs in California were most enlightening and certainly provided insight in the interpretation of our empirical results. TMCs represent an integration of hardware and people. Our priors before undertaking the case study was that process and management were most important in ensuring the TMCs had added value. The TMC hardware is an integration of ITS investments with the important addition of information and, hopefully, coordination. This all boils down to management and what we found is the institutions with their designation of responsibilities, who can do what, when and where, requires some change before the TMC can be an effective addition to the management of the transportation network.

Our second modeling approach was to estimate a set of performance related regressions based on data for all counties in California. The performance measures were levels and changes in congestion (measured by a congestion index) and changes in VMT for autos and trucks. The former is a measure of reducing externalities while the latter two were more measures of efficiency. We found that for auto VMT ramp meters were more important than CMSs in improving the system. This was, more VMT can be obtained from the system, holding congestion constant, with ramp meters. We found that TMCs had no statistical impact on auto VMT. In the case of truck VMT, the results were just the reverse; CMSs appeared to be more important than ramp meters in improving system efficiency when efficiency was measured by extracting more truck VMT from the system, holding congestion constant. As with the auto results, TMCs were not significant in the analysis.

The regression using the congestion index found the statistical results although somewhat weak illustrates that controlling for county differences, ramp meters and CMSs reduce congestion, as measured by the index. Ramp meters appear to be 4 times as effective as CMSs. TMCs as before were not statistically significant in affecting congestion. Overall the model does not seem to have a lot of explanatory power in sorting out the differences in congestion among counties or what the underlying contribution is of ITS relative to investments. But it is evident that among conventional congestion relief measures maintaining infrastructure (roads) is more effective than expanding capacity. It also appears that ramp meters and CMSs, indicators of improved network management are more effective in reducing congestion than are expanding the network.

Our third modeling effort was an attempt to see if there was an ‘S’ curve effect in which a change in the network due to an ITS investment or the introduction of a TMC leads to a regime change. If so, the change would result in a disequilibrium, which over time would result in a new equilibrium position for the system. If one measured the impact of the investment too soon, in the disequilibrium period, it would underestimate the true contribution of the investment or change in process or management strategy. We used a new technique designed specifically for this purpose and used extensively in the macroeconomics and finance literature. Unfortunately, even though our first stage test showed evidence of turning points, the second stage tests were not statistically robust in defining the turning points. We were particularly interested in when and whether the ITS and TMC investments led to subsequent regime changes in VMT and congestion. It may have been asking too much of the data but more likely, in keeping with the other results, it was showing that TMCs as now structured are unlikely to have any significant value added in the management of California’s transportation network.

GLOSSARY

Advanced Traffic Management System (ATMS) - plays a pivotal role in intelligent transportation systems (ITS) by efficient, real-time management of the traffic system. ATMS roles include adaptive signal control, road access control, rapid incident response, adaptive traffic rerouting, and communication with drivers through in-vehicle and external communication media. The ATMS is the instrument of effective traffic control in a given ITS service area and the Traffic Management Center (TMC) is the "brain" of that system.

Closed-Circuit Television (CCTV) - A surveillance system consisting of a remote camera that is controlled through direct wiring (or non-broadcast aerial transmission) to a television-style monitor. The camera usually has full remote control of pan, tilt, and zoom from the workstation where the monitor is located.

Computer-Aided Dispatch (CAD) - combines computer and communications technologies to better manage communications among emergency responders and their dispatch centers. Computer-aided dispatch systems are in place in thousands of fire, police, and other emergency service agencies throughout the country.

Highway Advisory Radio (HAR) – short-range AM radio with transmitters located within the freeway right-of-way to provide motorists with advanced traffic information messages. Extinguishable roadway signs signal the presence of HAR messages and the appropriate radio station to motorists. HAR is activated from within the TMC.

High Occupancy Vehicle (HOV) lanes - are lanes that are restricted at specified times of the day to vehicles with at-least a certain number of people (usually 2 or 3).

Incident - any event that dramatically affects the flow of traffic on a roadway by blocking lanes, slowing traffic flow, and/or drawing excessive undue attention from passing drivers. Typical incidents could include accidents, disabled vehicles, roadway debris, or police and fire emergencies visible from the roadway.

Intelligent Transportation System (ITS) - the application of advanced information, navigation, and communication technologies, along with sophisticated institutional arrangements and operating procedures, to better manage the performance of a transportation system.

Loop Detectors - are in-pavement devices that generally use magnetic field technology to detect the presence and/or passage of vehicles in a roadway traffic lane. Loop detectors can be used to count traffic, measure speed or lane occupancy, classify vehicles by type (a measure of size), or to provide a detection mechanism for controllers that operate traffic signals and ramp meters. Servicing loop detectors requires opening up the pavement and can cause serious disruption, particularly in high-traffic areas..

Microwave Radar Detectors - are one form of non-intrusive detection. With microwave radar detection, microwave energy is beamed onto the detection area from a radar sensor mounted either above or beside the roadway. Vehicle presence and speeds are detected by frequency changes in the return signal. Unlike inductive loops or magnetometers, both of which require, to differing degrees, dismantling the pavement, non-intrusive traffic surveillance sensors are mounted on a structure above the roadway surface.

Probe Vehicle - a vehicle equipped with position- and time-sensitive data collection equipment, and a means of communicating this data; or, a vehicle equipped with a self-identification transponder such that roadside devices can track the vehicle's movement.

Ramp Metering - traffic-sensitive or time-based regulation of vehicle entry onto a freeway using sensor-controlled stop lights at freeway on ramps or connector ramps

System Wide Adaptive Metering (SWARM) - ramp metering that adjusts for traffic conditions throughout the system as opposed to simply using freeway flow rates from adjacent detectors.

Traffic Management Team (TMT) - a team of Caltrans personnel called out for serious incidents when on scene traffic management (portable changeable message signs, ramp closures, traffic diversion) may be necessary.

Variable message signs (VMSs) - or changeable message signs (CMSs) are a primary means of communication between the TMC and the driver. Under normal traffic conditions, the VMS sign is either blank or, in a few centers, it contains a generic message such as a safe driving admonition or the distance to the next exit. When drivers are to be warned of an emergency, advised to change routes, or guided to a particular location, an appropriate message is posted.

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