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16. Abstract
This report summarizes a literature review and interviews with many persons active nationally in congestion management. Telephone contact was made with all the state departments of transportation and numerous local agencies, metropolitan planning organizations and personal contacts throughout the country. These telephone contacts helped define the status of congestion management as of late 1992 and early 1993. The literature review found very little information. However, the interview process revealed that significant material was being developed in the first half of 1993. Most of this CMS related work was in response to state legislation (California and Washington), local recognition of congestion issues (Tucson) and anticipation of the ISTEA requirements relative to the management system. These interviews uncovered many documents that have been incorporated into this report. On site interviews were conducted with twenty local agencies and five state departments of transportation.

The findings are summarized into specific recommendations on the measure of congestion, definition of the CMS network, monitoring the CMS network over time, and administration of the CMS Program. The report has several appendices which contain detailed information drawn from the site visits and other information which may be helpful to MPO's and state highway agencies. The final chapter of the report includes specific recommendations for FHWA and FTA to consider in the implementation of the CMS Program at the Federal level.

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CONGESTION MANAGEMENT SYSTEMS STATE-OF-THE-PRACTICE-REVIEW

Project 9-593
Congestion Management Systems State-of-the-Practice

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IMPLEMENTATION STATEMENT

The findings of this research can be used to guide the implementation of the 1991 ISTEA CMS requirement at the Federal, State and local government levels. The experience in several locations has been reviewed and the suggestions from operating personnel concerning the requirements are cataloged. Earlier drafts of this report, as well as individual site visit reports, were provided to FHWA and FTA to assist in the rule making process.

Suggestions for implementation of congestion management systems are detailed in a series of recommendations on:

1) determining the measure of congestion;
2) defining the CMS network;
3) monitoring the level of congestion on the CMS network; and,
4) organizing the shareholders in the management of congestion into an effective force for full implementation of the CMS program.

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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration, the Federal Transit Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. This report prepared by: Robert A. Hamm, Donald L. Woods (Texas Professional Engineer License 21315), Vergil G. Stover (Texas Professional Engineer License 26979), and Patrick E. Hawley.

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LIST OF ABBREVIATIONS

ADA   - American Disabilities Act
AOG   - Association of Governments
ARB   - Air Quality Regulation Board
AVI   - Automated Vehicle Identification
AVO   - Average Vehicle Occupancy
CAAA   - Clean Air Act Amendments of 1990
CALTRANS - California Department of Transportation
CBD   - Central Business District
CATS   - Chicago Area Transportation Study
CCTA   - Contra Costa County Transportation Authority
CDTC   - Capital District Transportation Committee
CMA   - Congestion Management Agency
CMAQ   - Congestion Mitigation and Air Quality Improvement Program
CMP   - Congestion Management Program
CMS   - Congestion Management System
COG   - Council Of Governments
CVAG   - Coachella Valley Association of Governments
DOT   - Department of Transportation
DVKT   - Daily Vehicle-Kilometers of Travel
ETTM   - Electronic Toll and Traffic Management
GOP   - Goal Oriented Program
GPS   - Global Positioning System
GIS   - Geographic Information System
HPMS   - Highway Performance Monitoring System
ICU   - Intersection Capacity Utilization
IFR   - Interim Final Rule
ISTEA   - Intermodal Surface Transportation Efficiency Act of 1991
LAC MTA   - Los Angeles County Metropolitan Transportation Authority
LRTP   - Long Range Transportation Plan
LOS   - Level-Of-Service
MKD   - Minute-Kilometers of Delay
MNDOT   - Minnesota Department of Transportation
MPO   - Metropolitan Planning Organization
MTA   - Metropolitan Transit Authority
MTC   - Metropolitan Transportation Commission
NPRM   - Notice of Proposed Rule Making
ODOT   - Oregon Department of Transportation
PAG   - Pima Association of Governments
RCI   - Roadway Congestion Index
RTF   - Running Time Factors
RCTC   - Riverside County Transportation Commission

LIST OF ABBREVIATIONS (Continued)

RGMP   - Regional Growth Management Program
RGMS   - Regional Growth Management Strategy
RME   - Regional Mobility Element
RTIP   - Regional Transportation Improvement Plan
SANDAG   - San Diego Association of Governments
SCI   - Suggested Congestion Index
SHA   - State Highway Agency
SMS   - Safety Management System
STP   - Surface Transportation Program
STP CMAQ   - State Transportation Planning Congestion Mitigation and Air Quality Funds
SRA   - Strategic Regional Arterial
TIPs   - Transportation Improvement Programs
TDM   - Transportation Demand Management
TMA   - Transportation Management Area
TMS   - Time Mean Speed
TSM   - Transportation Systems Management
USDOT   - United States Department of Transportation
VKT   - Vehicle-Kilometers of Travel
VHD   - Vehicle-Hours of Delay
WRCOG   - Western Riverside Council of Governments

SUMMARY

This document presents a synthesis of congestion management practices. Contacts with representatives of state and local agencies provided the base data. State highway agencies were contacted in late 1992 to determine their current and near-term expected Congestion Management System (CMS) practices. Also, telephone contacts with numerous local agencies, Metropolitan Planning Organizations (MPOs), and individuals identified potential data sources. A survey conducted as a part of National Cooperative Highway Research Program (NCHRP) Project 7-13, "Quantifying Congestion," provided a list of agencies and individuals involved in congestion management activities. On-site visits were made to twenty local congestion management agencies and four state Departments of Transportation (DOTs). Sites were selected by the project staff in cooperation with the Federal Highway Administration (FHWA). The on-site visits included a few small area MPOs to facilitate an assessment of problems that are unique to urban areas of less than 200,000 population.

Several sites were in California. They are in an advanced stage of CMS practice. Congestion management was mandated at the county level by state legislation in 1991. Therefore, California counties have two years experience with congestion management practices. Growth management legislation by the Washington Legislature, and a local initiative by the Pima Association of Governments (Tucson) provides insight in the CMS process. Significant data also came from the joint project by the Colorado DOT and the Pikes Peak (Colorado Springs) Council of Government (COG); and from the Denver Area COG. The program of the Capital Area Transportation Committee (the COG for the Albany, NY area) also resulted in insight on the early consideration of the CMS requirements in project planning. Site visits with congestion management personnel throughout the nation form the core of this report. Information as to successful congestion management activities as well as the identification of practices that do not work well came from these interviews. The results include many suggestions for improving the CMS process.

The general impression of the interviewers and the apparent utility of the suggestions offered form the basis of the findings in this report. Most notable among the findings is that level-of-service is not perceived as a good area-wide measure of congestion. Although widely used to evaluate operational conditions, it does not permit direct measurement of multi-modal congested travel. Travel rate (minutes per mile or per kilometer) is the best measure of congestion. This is especially true where multi-modal auto, transit or truck transportation is of interest. A (volume)/(acceptable capacity) ratio is the best measure of congestion for small urban areas with low percentage of trips by transit and in rural areas. The lack of control of access to arterial streets, poor signalized intersection spacing and the lack of control of medial traffic movements are major factors contributing to the obsolescence of arterial streets and the resulting congestion. The recommendations reflect this concern. Other significant findings include the following:

1)   Participation of 30% of employees in a ridesharing program is the practical upper limit for most businesses. Achieving and maintaining a higher participation rate is difficult, time consuming and expensive.

2)   CMS policies and rules, to the degree possible, should provide achievable goals. Local government should find the best way to meet the goals from a wide range of "tools" that are available.

3)   Access to new money is the most powerful incentive to local government participation.

4)   Minimizing the cost of congestion mitigation measures imposed on individual businesses is important. This is especially true when imposing trip reduction requirements where the benefits (reduction in congestion) are marginal, uncertain or largely a matter of conjecture.

5)   Expressions of concern from some transportation agencies that the environmental agencies are unwilling to compromise in the best interest of the community regarding the tradeoffs of economics, jobs, mobility and air quality.

The concluding chapter details the list of recommendations for the Federal Highway Administration and the Federal Transit Administration for consideration in their technical assistance programs for implementation of CMS programs across the nation. The recommendations include the following items.

1. Travel Rate is the best general measure of congestion.
2. The CMS network should be defined on the basis of vehicle-kilometers of travel.
3. The CMS network should be formally adopted by the CMS agency board.
4. System monitoring as a minimum should be all freeway section , all links previously defined as congested, and links approaching congested operation.
5. The CMS network should be reviewed and updated on a regular basis.
6. CMS data should not be taken where the Measure of Effectiveness (MOE) might be affected by construction and/or maintenance activities.
7. The CMS annual report should be very brief easily readable
8. The "Goals Oriented" approach of New York State should be examined as a model to use in the implementation of congestion management.
9. The CMS structure should have only on designated CMS agency in each metropolitan area.
10. A policy of access control of arterial streets should be adopted by CMS agency.
11. The air quality agency should be a full member of the CMS decision making board and should not have veto power on recommendation reached by mutual agreement.
12. An environmental master agreement should be considered for use by each metropolitan area.
13. CMS implementation should recognize the practical upper bound on ridesharing of 30% in any given business.

14. CMS strategies should emphasize incentives to meet trip reduction ordinances rather than penalizing businesses for failing to meet work site vehicle occupant targets.

15. An ordinance that details mitigation fees for traffic impacts of new development should be adopted by each CMS agency.

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CHAPTER 1
INTRODUCTION

The Clean Air Act Amendments of 1990 (CAAA) and the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) greatly impacted the nation's transportation programs. State and local officials have been given increased funding, added flexibility to select projects to meet local needs, and enhanced metropolitan and statewide planning requirements. Metropolitan Planning Organizations (MPOs) have been given increased responsibility for planning and implementing projects within their jurisdiction in order to improve mobility.

Status of Congestion

Traffic congestion has been a problem in the United States for many years and is growing increasingly worse at an alarming rate. Vehicle-hours of delay, wasted fuel, and user costs increased by more than 60% between 1984 and 1987(1). By the year 2005, each of these losses are expected to more than triple. Furthermore, urban freeway delay caused by non-recurring incidents is expected to increase 71% by 2005. This emphasizes the need for increased management and better use of the existing capacity.

Another recent study (2) examined traffic conditions in 50 of the largest cities in the nation. Nearly half of the nation's urban areas have experienced between 17 and 23 percent increases in congestion since 1982. Since the beginning of the study in 1989, only three cities (Detroit, Houston, and Phoenix) have shown a decrease in congestion with Houston being the only city to show a continual decrease each year since 1984.

Congested conditions in all 50 cities were evaluated using the roadway congestion index. The index is a ratio of urban area daily vehicle-kilometers of travel (DVKT) per lane for freeways and principal arterial streets to DVKT per lane values identified with congested conditions, as shown below.

$$RCI = \frac{\left[\dfrac{Freeway}{VKT/Ln-km} \times \dfrac{Freeway}{VKT} + \dfrac{Prin\ Art\ Str}{VKT/Ln-km} \times \dfrac{Prin\ Art\ Str}{VKT}\right]}{\left[13{,}000 \times \dfrac{Freeway}{VKT} + 5{,}000 \times \dfrac{Prin\ Art\ Str}{VKT}\right]}$$

An index value greater than 1.0 indicates an undesirable level of areawide congestion. The Roadway Congestion Index (RCI) values have been computed for each of the 50 cities in the study since 1982. Inspection of these RCI values showed that they fall into five groups. The RCI values were averaged for the different population groups and are shown in Figure 1-1. As expected, congested conditions for the largest metropolitan areas are worse than conditions in smaller areas. However, congestion levels are growing increasingly worse in all areas at an alarming rate regardless of population.
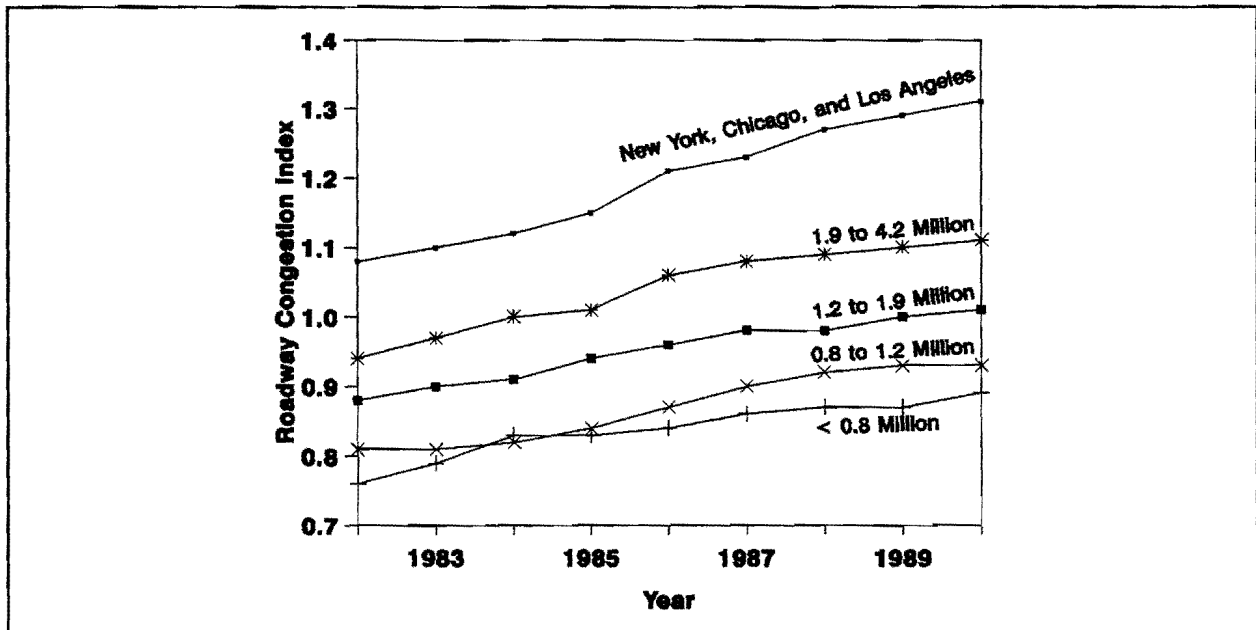
**Figure 1. Roadway Congestion Index Values Grouped by
Population (Millions), 1982 to 1990**
SOURCE: Adapted from Reference (2), p. 56.

The study also estimated the cost of congestion at $43.2 billion in 1990. This is a 10% increase from the 1989 cost of $39.2 billion. The cost was estimated based on congested peak-period VKT (VMT) on freeways and principal arterial streets and included estimates of fuel consumption and travel delay for all urban areas in the study. Five values were held constant for all urban areas; average vehicle occupancy (1.25 persons per vehicle), working days per year (250), average cost of time ($10 per person-hour), commercial vehicle operating cost ($1.95 per mile) and vehicle mix (95% passenger and 5% commercial).

The skyrocketing costs of congestion and the similar rate at which congestion is increasing in all urban areas emphasizes the need for Congestion Management Systems (CMSs) in all parts of the country. Both small and large metropolitan areas can benefit from a CMS in reducing public costs and halting the growth of congestion.

Federal Requirements

Metropolitan Planning Organizations, especially those which have a population of over 200,000 and are thus designated as a Transportation Management Area (TMA), have been given increased responsibilities in the transportation planning process. The planning process must now address additional considerations such as land use activities, intermodal connectivity, travel demand management, and needs identified through the management systems. MPOs have increased responsibility for projects within their area although the state retains responsibility for Interstate highways, facilities on the National Highway System and defense roads. The State is also required to develop a statewide planning process, a statewide transportation plan, and a statewide transportation program.

Additionally, the State must design, establish, and implement six management systems, including a Congestion Management System, plus a Traffic Monitoring System. A Congestion Management System (CMS) was defined in the Notice of Proposed Rule Making (NPRM, §500.503) as "a systematic process that provides information on transportation system performance to decision makers for selecting and implementing cost-effective strategies to manage new and existing facilities so that traffic congestion is alleviated and the mobility of persons and goods is enhanced." Comments received in response to the NPRM indicated that several persons misinterpreted this definition to imply that the CMS only involved data collection since the CMS was a process that provided information (78, 63463). The Interim Final Rule (IFR) (78,§500.503) avoids this potential misinterpretation and defines the CMS as follows:

Congestion management system (CMS) means a systematic process that provides information on transportation system performance and alternative strategies to alleviate congestion and enhance the mobility of persons and goods. A CMS includes methods to monitor and evaluate performance, identify alternative actions, assess and implement cost-effective actions, and evaluate the effectiveness of implemented actions.

Congestion means the level at which transportation system performance is no longer acceptable due to traffic interference. The level of acceptable system performance may vary by type of transportation facility, geographic location (metropolitan area or subarea, rural area) and/or time of day.

The CMS must cover the entire state, but may consist of sub-systems for each metropolitan area and non-metropolitan area. The State and/or MPO must define an appropriate network of roadways which cover the area of consideration. This network will be evaluated based on an acceptable level of system performance for that area. A continuous data collection and system monitoring program needs to be established in order to measure and monitor congestion on a regular basis. Following the identification of congested areas, a series of proposed strategies, both traditional and nontraditional, need to be evaluated to ensure the efficient use of the network.

It needs to be recognized that the CMS must identify the extent of expected congestion (forecasts of congestion) in addition to providing information on current network performance (existing congestion).

Project Description and Scope

The primary objective of this project was to document the state-of-the-practice of current congestion management activities in the United States. This includes congestion measurement and monitoring practices, appropriate definitions of congestion, current institutional constraints, creating and defining an appropriate congestion management network, the data needed for congestion management decision making, project implementation practices, and costs associated with data collection and implementation practices.

The literature review included documentation on the current state-of-the-practice in congestion management. The majority of these documents were used in the compilation of this report and are listed in the back in the references section. In addition, an exhaustive literature review on Congestion Management Systems was completed by a private consultant for the Pima Association of Governments in October 1992 (3).

The initial activity on this State-of-the-Practice review began with contact with all fifty state DOT's and numerous MPO Directors during October and November 1992. This contact was designed to determine what congestion management activity existed in each agency. From these contacts, the study sites were selected jointly by the research staff and the Federal Highway Administration staff. The sites reflect a wide variety of urban area sizes as well as urban and rural states.

Twenty-six sites were selected and visited between Tuesday, February 16, 1993 and Tuesday, June 29, 1993. The sites consisted of state and local agencies in different geographic regions across the country and in areas with both high and low populations. A list of all agencies visited and their location is included in Table 1-1. Each site visit was conducted by either Dr. Donald L. Woods or Dr. Vergil G. Stover of the Texas Transportation Institute and Texas A&M University. In addition, Mr. Ron Giguere or Mr. Brian Hoeft of the Federal Highway Administration participated in several of the visits.

Information was obtained from various agencies regarding the definition of congestion, current practices involving congestion measurement and monitoring activities, institutional constraints and conflicts, and strategies currently considered or implemented to help alleviate congestion. A complete site visit schedule, including principal contacts and those in attendance, is included in Appendix A. In addition, the result of each site visit was documented in a technical memorandum. These technical memoranda were used as a basis for Appendices E, F, G, H, I, J and K.

Twelve of the 26 site visits were completed to various agencies in California because of their previous experience with state mandated congestion management programs. In June 1990, before the passage of ISTEA, California voters passed a law requiring each county with an urbanized population over 50,000 to create a congestion management agency. These agencies have spent the last three years designing and implementing congestion management programs. Each agency provided important insight into the development of their program, including problems to avoid. The California legislation has also helped provide FHWA with an idea of what specific requirements should be included in the Federal Requirements and which requirements should have flexible procedures.

The California legislation, Propositions 108 and 111, increased the fuel tax by 9 cents per gallon and authorized bonds for rail transit which together are expected to generate $18.5 billion to fund transportation investment statewide over the next 10 years (4). As a condition for receiving the new fuel tax, each urban county in the state must develop and annually update a Congestion Management Program (CMP). Some counties designated an existing agency, such as the MPO or Transportation Authority, to serve as the designated

Table 1-1. List of Site Visits

NAME OF AGENCY	CITY	STATE
1. Alameda County Congestion Management Agency	Hayward	California
2. Bay Area Metropolitan Transportation Commission	Oakland	California
3. Bi-State Regional Commission	Rock Island	Illinois
4. California Department of Transportation, District 4	Oakland	California
5. California Department of Transportation, District 11	San Diego	California
6. Capital District Transportation Committee	Albany	New York
7. Charlotte Department of Transportation	Charlotte	North Carolina
8. Chicago Area Transportation Study	Chicago	Illinois
9. Colorado Department of Transportation	Denver	Colorado
10. Contra Costa Transportation Authority	Walnut Creek	California
11. Denver Regional Council of Governments	Denver	Colorado
12. Los Angeles County Metropolitan Transp. Authority*	Los Angeles	California
13. New York Department of Transportation	Albany	New York
14. North Carolina Department of Transportation	Raleigh	North Carolina
15. Pikes Peak Council of Governments	Colorado Springs	Colorado
16. Pima Association of Governments	Tucson	Arizona
17. Puget Sound Regional Council	Seattle	Washington
18. Riverside County Transportation Commission	Riverside	California
19. San Diego Association of Governments	San Diego	California
20. San Diego Transportation Management Association	San Diego	California
21. San Joaquin County Transportation Commission	Stockton	California
22. Santa Clara County Congestion Management Agency	San Jose	California
23. Southern California Association of Governments	Los Angeles	California
24. SW Washington Regional Transportation Council	Vancouver	Washington
25. St. Cloud Area Planning Organization	St. Cloud	Minnesota
26. Washington Department of Transportation	Olympia	Washington

*Note: The Los Angeles County Transportation Commission and the Southern California Rapid Transit District merged in January 1993 to form the Los Angeles County Metropolitan Transportation Authority. The merger was caused by California Assembly Bill 152.

congestion management agency for the county. These agencies perform congestion management activities in addition to their current responsibilities. Other counties created new Congestion Management Agencies (CMAs) which only have the authority for congestion management activities. A summary of the California State requirements is given in Appendix D.

The California sites were selected due to their two-years of experience with congestion management. Sites in the State of Washington reflected extensive growth management strategies. The Bi-State Regional Commission was included due to their active involvement as a small metropolitan area consisting of multiple local governments located in two states (Iowa and Illinois). It was reported to have a very effective planning process. The Capital District Transportation Committee of Albany, New York uses a unique goal

oriented approach to congestion management and an interesting method of defining congestion.

The Chicago Area Transportation Study was responsible for the "Operation Green Light" project in the Chicago Area. The Colorado sites were of interest as they had specifically addressed the issues involved in defining congestion. These include the different problems and public perceptions in an urban area having a limited number of local political jurisdictions (the Pikes Peak COG, Colorado Springs) the much larger Denver area (Denver Regional COG) and the remainder of the state. The fact that the Colorado DOT, the Pikes Peak COG and the Denver Regional COG were cooperating in a joint study to identify and address congestion management issues was a major factor in selecting these sites.

North Carolina offered a unique view of managing the entire system since NC DOT has jurisdiction over all roadways outside of municipalities and works very closely with the local jurisdictions. Pima County, Arizona had an on-going CMS type program long before ISTEA was approved. This site reflects, to a large degree, the state-of-the-practice of congestion management at the metropolitan area level. The St. Cloud, Minnesota Area Planning Organization was reported to have an outstanding traffic data collection system for a small urbanized area. These data were deemed to have potential value in state wide congestion management systems planning and implementation.

CHAPTER 2
CONGESTION MANAGEMENT SYSTEM STRUCTURE

A CMS can be viewed as a monitoring, forecasting, and analysis process which identifies alternative strategies, assesses their potential effectiveness and develops a program to be implemented. Such a process is a proactive approach to maintain or improve mobility and air quality through an action plan to relieve existing and anticipated future traffic congestion. Thus, CMS is the continuous activity of considering and implementing actions that enhance mobility and reduce congestion on designated roadways or in targeted areas.

Congestion management should be viewed in the context of the overall planning process. For example, the CMS should relate the goals and objectives of the regional long-range transportation plan recommendations and policies. This leads to development of local and regional (MPO) Transportation Improvement Programs (TIPs). Also, the state-wide CMS will help identify strategies for incorporation into the State Transportation Improvement Program (STIP).

A CMS should support the development and implementation of transportation system management (TSM) and transportation demand management (TDM) programs and policies through an assessment of the potential effectiveness of TSM and TDM. A CMS should also support the air quality goals of the community through the implementation of policies, programs, and transportation system improvements that maintain or improve air quality.

At a minimum, an effective CMS should contain the following six elements:

- Identification of targeted roadways to be included in the planning effort;
- Identification of system performance measures and objectives;
- A process of ongoing data collection and system monitoring;
- A procedure for evaluating system performance, and changes in performance over time, including the evaluation of land use development proposals or changes in land use;
- Multimodal congestion reduction including the use of TSM and TDM strategies; and
- A process for identifying the specific responsibilities of each agency and jurisdiction involved in the CMS.

It should be recognized that CMS is substantially different from transportation system management of the 1970's. These differences include the following.

- CMS emphasizes implementation and the role of implementing agencies, State and local agencies must establish an institutional structure for making congestion management decisions.

- CMS includes a systematic process for continuous data collection and congestion monitoring. CMS also includes projecting where, and to the extent, congestion will occur in the future. Both of these aspects were absent in transportation systems management as practiced prior to the passage of the ISTEA.
- CMS places more emphasis on integrated multimodal and TDM strategies.
- CMS involves a linkage with the 1990 Clean Air Act Amendments requirements, congestion management strategies, and land use decisions.

CMS represents a significant step towards furthering interagency and interjurisdictional coordination in the implementation of congestion management strategies and achieving air quality goals. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) defines urbanized areas with a population over 200,000 as Transportation Management Areas (TMAs). In all TMAs the CMS shall be a part of the metropolitan planning process (<u>78</u> §500.505 (d)). Thus, in these areas, the MPO must have a significant role in the CMS. Additionally, where a TMA is designated as an air quality nonattainment area, the CMS shall provide an appropriate analysis of all reasonable travel demand reduction and operational strategies for a corridor which the project will result in a significant increase in single occupancy vehicle capacity (<u>78</u> §500.505 (e)). In order to effectively address congestion issues, MPOs which are not a TMA, should also make CMS a part of their metropolitan transportation planning process. At the very least a CMS must be developed by the State in cooperation with the MPOs having a population less than 200,000.

ISTEA requires that States institute a statewide planning process, develop a statewide transportation plan and prepare a statewide transportation improvement plan (<u>79</u>). It also makes each Metropolitan Planning Organization (MPO) responsible for developing, in cooperation with the State and transit operators, a long range transportation improvement plan for its area. Additionally, ISTEA makes the State responsible for the development and implementation of the six management systems as well as the Traffic Monitoring System. While the CMS, and other management systems, must be implemented on a statewide basis, the State may define subsystems within the state and delegate responsibility for development and implementation of the CMS to local agencies.

While CMS is a separate requirement, it relates directly to a variety of statutory and regulatory requirements as well as the other five management systems and the traffic monitoring system required by the ISTEA legislation. Other factors, such as growth management and concurrence requirements, will influence the structure and implementation of a CMS in some states. Growth management requirements require developments and the transportation network to be mutually compatible and not cause an overload of the transportation system. Concurrence requirements insure that the funding for transportation improvements are available before development can occur.

The primary purpose of CMS is to provide additional information needed to make more effective decisions on the use of limited resources to protect the investment in and improve the effectiveness of the existing and future transportation network. The CMS must

provide overall measurement and monitoring of mobility - not just roadway performance. This approach is necessary because many of the decisions relative to the roadway system will directly affect bus transit operators and goods movement by truck. Furthermore, a CMS must identify proposed strategies to make more efficient use of existing and future transportation facilities, evaluate their potential effectiveness, singularly or in combination, and develop an implementation program as to schedule, responsibilities and funding.

As will be discussed in a later section of this chapter, the MPO has responsibility for the metropolitan transportation planning process and development of the long range transportation plan (LRTP) for its metropolitan area. The CMS must be an integral part of each MPOs transportation planning process. Thus, the MPO must have a major role in the CMS although the State has ultimate responsibility for the statewide CMS. The local governmental jurisdictions will also need to be fully integrated into the CMS, the transportation planning process and development of the TIP since these municipalities and counties will be primarily responsible for implementing the transportation control measures (TCM) and land use controls. Effective cooperation will be required between the MPOs and the state DOT in order to integrate the TIP for each metropolitan area into STIP.

Many players need to be included in the development and implementation of a congestion management system. Several governmental and stakeholder organizations all have an interest in the design and implementation of a CMS, as shown in Figure 2-1. It is important to develop an understanding of the objectives of and commitment to the CMS to be implemented. All of these agencies and organizations must cooperate in order to develop and implement a successful CMS program.

It is essential that all parties which have a stake in the policies and actions which may be implemented under a CMS play an active role in the development of the CMS. This is especially true for the definition and measure of congestion discussion and the identification of the CMS network, the first key elements of the Congestion Management process.

Congestion measurement is broader than just auto transportation. It must be mobility based so that evaluations between auto, bus and rail transit can be addressed. This view was expressed by various agencies during the site visits. Congestion management also needs to consider bus transit and trucking since these modes operate over the street and highway system. This view was also expressed by the National Association of Regional Councils in a paper entitled "A Discussion of Management Systems in the ISTEA" with the following goal statement:

> ". . . it is the congestion management system which should provide the central basis for evaluating multi-modal system performance, defining system needs, and for determining operating and capital investment strategies for system preservation and enhancement. In doing so, the CMS should logically integrate the other management systems."

Figure 2-1. The Players in a CMS Program
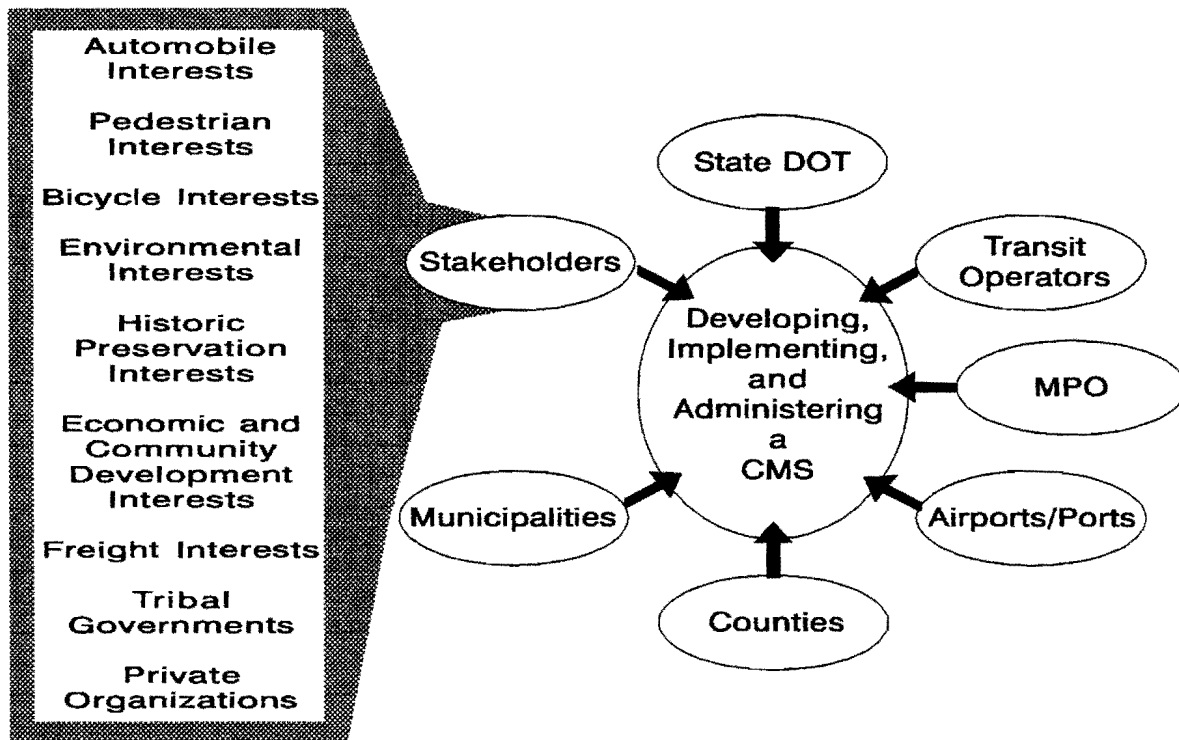
One agency should have the leading role for congestion management for the entire metropolitan area. The exception to this general guideline is the case of very large urban areas. Subarea responsibilities may be necessary due to the scope of the data collection and analysis effort in very large urban areas. In either case, several agencies must work together for the CMS to be successful.

Structure and Roles

The objective of CMS and the other management systems is to protect and enhance the transportation infrastructure. In TMAs, the CMS is to provide effective management of existing and future transportation facilities eligible for funding under title 23 USC and under the Transit Act. If the management systems are to be effectively utilized in urban areas, they must be an integral part of the metropolitan planning process of MPOs in both TMAs and non-TMAs. This logically follows from the fact the metropolitan planning process involves the evaluations of land use-transportation alternatives, the assessment of the effectiveness of changes in the transportation system to improve mobility and safety, evaluation of land use policies and development proposals, assessment of TDM and TSM actions individually or in combination, etc. This relationship between the management systems and the planning process is illustrated in Figure 2-2.

The MPO has primary responsibility for the planning process in urban areas. Hence, integration of the management systems into the planning process, the transportation plan, and TIP leading to effective implementation necessitates that the MPO have a very

Figure 2-2. The Planning Process Incorporating the Management Systems
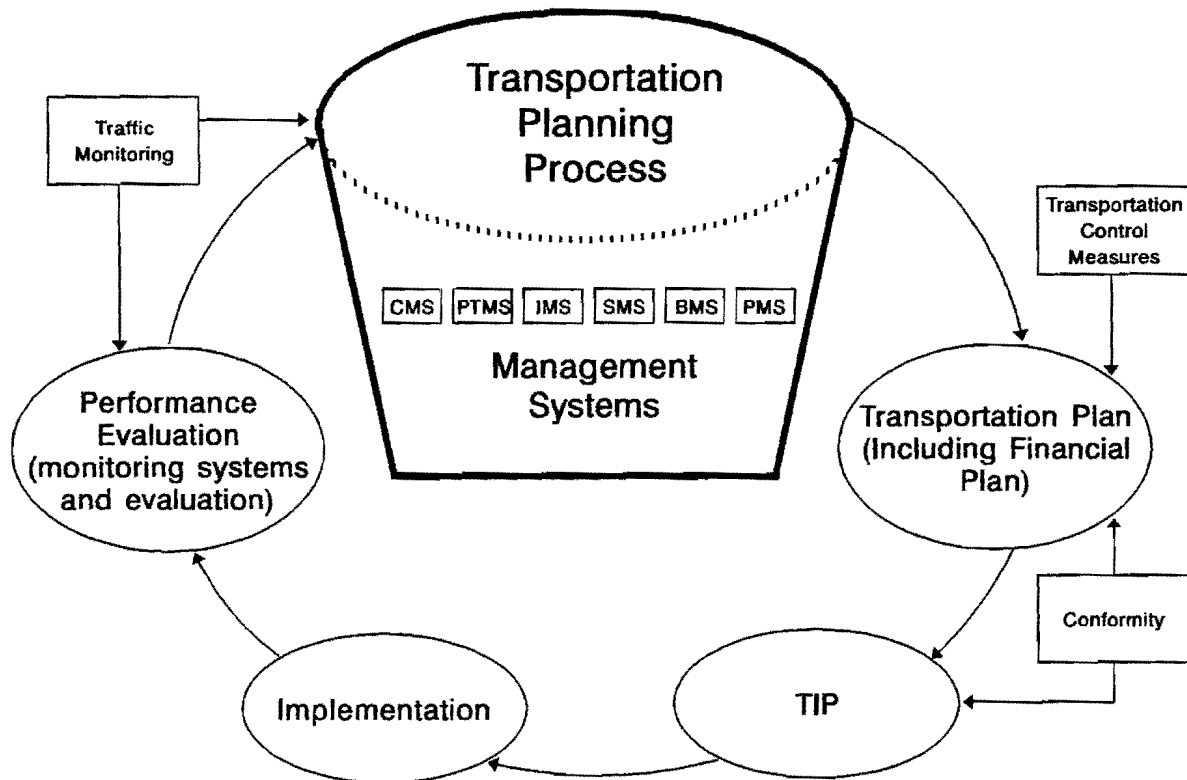
prominent role in CMS and the other management systems as they relate to transportation facilities within their geographical areas of concern.

However, the ISTEA makes the state highway agency (SHA) primarily responsible for the management systems. The ISTEA also provides delegation of responsibilities by the SHA to MPOs. Hence, this dichotomy between responsibility for the metropolitan planning process and responsibility for management systems can be resolved by the SHA by 1) delegating significant responsibility for the CMS to the MPOs and 2) working closely with the MPOs throughout the planning process. A generalized structure for a CMS program is suggested in Figure 2-3. Possible roles for the various agencies are given in Table 2-1.

Summary of Findings

The site visits and telephone contacts indicate that there are a variety of organizational system structures being developed to deal with congestion management issues. Based upon the state-of-the-practice review, some guidelines to successful implementation of CMS can be stated as follows:

1)   The implementation requirements should be as flexible as possible, so as to allow each metropolitan area to implement and administer a CMS which best meets their specific needs as well as allow the state highway agency to address the state interests. Hence, local governments might be given broad latitude

Table 2-1. Possible Roles for Elements of a Congestion Management System

CMS Activity	Role			
	State DOT	MPO	City, County	Transit Operator
Organizational				
Provide Forum & Discussion	P	L	P	P
Define Boundaries	C	-	P	P
Delegate Responsibility	L	P	P	P
Bi-State Agreements	L	P	P	P
Identify Performance Evaluation Standards				
Provide Forum & Conflict Resolution	C	L	P	P
Select Measure	P	L	P	P
Select Standards	P	L	P	P
Define the CMS Network				
Provide Forum & Discussion	P	L	P	P
Establish Criteria	P	L	P	P
Data Collection, Monitoring and Performance Evaluation				
Provide Forum & Discussion	P	L	P	P
Identify Data Needs	P	L	P	P
Develop Definitions & Submission Protocol	P	L	P	P
Define Methodology	P	L	P	P
Provide Traffic Counts	P	C	P	-
Provide Transit Data	-	C	-	P
Perform Baseline Evaluation	P	L	P	P
Identify Baseline Deficiencies	P	L	P	P
Performing Forecasts	P	L	P	P
Identify Future Deficiencies	P	L	P	P
Data Dissemination	P	L	P	P
Maintain Database	P	L	P	P
Identify and Evaluate Improvement Strategies				
Provide Forum & Discussion	P	L	P	P
Identify Candidate Strategies	P	C	P	P
Evaluate Strategies	P	C	P	P
Implementation				
Provide Forum & Discussion	P	L	P	P
Develop Program Criteria	P	C	P	P
Develop Implementation Program	P	C	P	P
Implement Program	P	C	P	P
System Administration				
Provide Forum & Discussion	P	L	P	P
Integrate with Management Systems	L	P	P	P
Evaluate Implemented Strategies	P	L	P	P

L: Lead - Initiate action or have primary role in achieving results

C: Coordinate - Combine information and data collection, perform analysis or provide central focus

P: Participate - Coordinate information, data, or analysis or performing specific implementation actions

Figure 2-3. A Generalized Structure for a Congestion Management System
SOURCE: Reference (24)

1 | *Organize the CMS Functions*
- Identify Boundaries & Responsibilities

2 | *Identify Performance Evaluation System*
- Measures   • Standards

3 | *Define Network*
- Existing   • Program Improvements
- Criteria for Establishing Network

4 | *Data Collection & Monitoring*
- Baseline Data   • Forecasts

5 | *Performance Evaluation*
- Baseline   • Future Year
- Identify Deficiencies

6 | *Identify and Evaluate Improvement Strategies*
- Local   • Corridor   • Areawide

7 | *Implementation*
- Cost   • Time-Frame
- Responsibility

8 | *System Administration*
- Evaluate Implemented Strategies

Other Management Systems
- Public Transportation
- Intermodal
- Safety

in selecting the combination of program elements on strategies to meet metropolitan and state objectives. A toolbox of alternatives similar to the ITE TDM course materials or the Pima Association of Governments Technical Memorandum #8 are recommended as references for those interested in TDM strategies.

2)   Careful consideration needs to be given to the cost that businesses will incur in implementing trip reduction strategies. For example, the San Diego Transportation Management Association determined that about 30% of the employees in a firm will volunteer to rideshare at any one time. Setting targets on average vehicle occupancy at the work place must be done in light of such constraints.

3)   In non-attainment areas, air quality management agencies should be responsible and equal parties in the CMS program development. They should not have dictatorial power over transportation and land use decisions as this often results in their unwillingness to negotiate in the best interest of the community because they have nothing to lose in the negotiation. The use of a master environmental impact policy and certification of each proposed project as being compatible to that policy should be seriously considered in lieu of a project specific environmental impact statement.

4)   All of the stakeholders must have an input into the CMS program and generally agree to a system of measuring congestion, TDM policies to be implemented and the scope of the mitigation actions to be taken when congestion is increased as a result of the development.

5)   Access management should be an integral part of all congestion management programs.

6)   The organizational structure selected must include a mechanism for integrating the impact of land use development decisions on congestion. This implies that land use changes approved by local governments will have the appropriate measures required of the developer to mitigate the impact of that change on congestion. The structure should also include the problem created in one political unit by development just over the boundary in an adjacent political unit.

No single organizational structure will be best for every state and local governmental unit. Following the suggested guidelines above will give the maximum opportunity for the management system to be successful in reducing congestion on the highway and street system.

CHAPTER 3
RECOMMENDATIONS FOR IMPLEMENTATION
OF CMS PROGRAMS

Measuring Congestion

The state-of-the-practice of congestion measurement suggests that there are many methods used to measure congestion. The most commonly used measure is Level-of-Service (LOS). This is probably the result of two factors: First, the California congestion legislation requires LOS in their CMS programs. Second, traffic operations personnel are commonly assigned the responsibility for the CMS program within an agency. Operations personnel are very familiar with LOS analysis and tend to propose its use for measuring and monitoring congestion.

Table 3-1 identifies various potential measures of congestion and the suitability of each for spot, corridor and area wide application. Due consideration should be given to transit, trucking and ferry modes (where applicable) in selection of the measure of congestion to use. A more detailed table exploring the potential measures of congestion is included in Appendix B, Methods for Defining and Measuring Congestion.

The consensus of those who have considered the problem of determining an area wide measure of congestion is that LOS is not an adequate measure of area wide multimodal congestion. There are three basic reasons for this opinion. First, LOS is point oriented and it is difficult to integrate the point LOS values into an area wide measure of congestion. Second, the LOS determination is based on a number of assumptions and computational techniques. This often results in different levels-of-service for the same roadway location. For example, using a different cycle length can change the LOS from F to D at a particular location. Third, the problem of projecting LOS to predict future congestion must be considered. There is no known method by which the turning movements for calculation of vehicular delay can be forecast with any degree of reliability. Since ISTEA requires projection of future congestion levels, it is concluded that LOS is not acceptable as a measure of area wide congestion. Moreover, LOS is limited to the vehicular highway and street transport mode and is not applicable to person mobility involving the automobile and public transit. Thus, LOS cannot be used as a multimodal or mobility based performance measure for congestion management.

The MPOs should adopt a measure of congestion consistent with the issues encountered in their region and use it uniformly throughout their area of responsibility. It is suggested that travel rate (that is, minutes per mile or kilometer) be used as the measure of congestion where multimodal transportation passenger and goods movement is of concern. Travel rate has the advantage of being relatively easy to determine, normally distributed, easy to integrate into a area wide measure of all modes, and sensitive to the changes in congestion levels. That is, the travel rate increases as the congestion level gets worse. This performance measure is especially appropriate for larger urban areas with mature transit systems.

Table 3-1. Potential Measures of Roadway Congestion*

Measure of Effectiveness	Application		
	Spot	Corridor	Areawide or Sub-area
Average travel speed		X	
Spot speed	X		
Average travel time[1]		X	
Average travel rate[2] [1]		X	X
Travel time contours[1]			X[4]
Total delay	X		
Excess delay	X	X	X[5]
Average delay per vehicle/per person	X		
Level of service	X		
Volume, flow rate	X		
V/C ratio	X		
Midblock volume/capacity[3]	X		
Congestion index[3]	X	X	X[5]
Roadway congestion index		X	X
Detector occupancy	X		
Minute-miles of delay		X	
Queue length	X		

*A more extensive list of potential measures of congestion is given in Table B-1 of Appendix B.

(1) Also applicable to transit.
(2) Minutes per mile, or kilometre.
(3) Congestion index: midblock volume divided by a flow rate which represents acceptable traffic volume conditions for the type of roadway (i.e. 2-lane, 4-lane undivided, 4-lane divided, intersection configuration traffic control, etc.), may be vehicles per hour or vehicles per day.
(4) Limited application since a travel time contour map relates to a specified origin and there is no procedure for aggregating maps.
(5) A weighted average (weighted by vehicle-miles of travel, vehicle kilometres of travel) can be used to obtain subarea or area wide measure. This weighted average is similar to the Roadway Congestion Index (See Appendix B).

Use of a volume to "acceptable flow" ratio is suggested as an alternative performance measure for small and medium sized urban areas where there is limited transit potential (less than 5% of person-trips by transit) and there are no transit oriented focal points (such as a University).

While an area wide measure of congestion is desirable, in some instances the differences between subareas within the metropolitan area may tend to mask the true effects of congestion. For example, if there are five subregions two of which have a high level of congestion and three have relatively little congestion, the single performance measure may very well indicate an acceptable level of congestion on the average. Subdividing the metropolitan area into a few relatively homogeneous subregions may well yield a better perspective of the congestion situation in the metropolitan area for the purpose of defining the congested areas of the community.

Defining Congestion

The level of traffic interaction at which congested operations begins is commonly defined as LOS D, E or F. LOS E and F definitions are mainly used in large metropolitan areas, such as the San Francisco Bay Area, the Los Angeles metropolitan area where higher levels of congestion are accepted by the travelling public. The LOS D definition is used in small and medium size metropolitan areas, such as Tucson, AZ, and Stockton, CA, where better operating conditions are possible.

As previously stated, LOS does not integrate directly to an areawide level of service, especially when intersection LOS is used. Nearly all agencies interviewed expressed dissatisfaction with using LOS as the measure of congestion. Other measures of congestion are more applicable for use in a CMS. Therefore, a recommendation of the definition of congestion based on LOS is not practical. A different measure of congestion should be used in defining congestion in order for CMS implementation to be effective.

Consistent with the travel rate recommendation for measuring congestion, an increase in travel rate would indicate congested operation. Based on the site visit interviews and traffic flow characteristics, suggested travel rates which represent congested conditions are shown in Table 3-2. Individual jurisdictions should select values which are appropriate for their area.

The measurement should be made over homogeneous geometric and traffic situations. The integration of the section travel rate into an areawide measure of congestion should be based on the weighted average travel rate in the defined network. The following equation can be used to calculate the average weighted travel rate for a multimodal (auto plus transit) transportation system:

Table 3-2. Suggested Travel Rates for Congested Conditions[1]

	Level of Conges-tion[2]	Travel Rate (minutes/mile)	
		Highway	Transit
Freeways or Transit on separate ROW	Moderate	1.3	1.3
	Heavy	1.7	1.7
Arterial Streets: Posted Speed, ≥ 45 mph	Moderate	1.7	3.7
	Heavy	2.0	4.0
Arterial Streets: Posted Speed, < 45 mph	Moderate	2.4	4.4
	Heavy	3.0	5.0

[1] Jurisdictions should select travel rate values which are acceptable and appropriate for their area.

[2] Moderate Congestion - Average running speed 10 mph below posted speed for a period of 15 minutes or more.

Heavy Congestion - Average running speed 15 mph or more below posted speed for a period of 15 minutes or more.

$$\bar{t} = \frac{\sum t_i L_i T_i O_i + \sum (t_i + tTER_i) L_i R_i F_i}{\sum L_i T_i O_i + \sum L_i R_i F_i}$$

Where $\bar{t}$ = weighted average area wide travel rate,

t_i = auto/truck travel rate on street section i (minute/mile),

$tTER_i$ = Terminal time (½ of transit headway with a maximum of 5, minutes divided by the length of the section L_i.

L_i = length of section i (miles or kilometers),

T_i = ADT on section i,

O_i = average auto occupancy on section i,

R_i = average ridership on transit vehicles in section i,

F_i = frequency of bus service (buses/hour) on section i.

NOTE: The $(t_i + tTER_i) L_i R_i F_i$ term can be used for transit on separate right-of-way, if t_i is the travel rate on the transit section.

This system wide travel rate is compared to a locally acceptable average travel rate such as Table 3-2 or similar values. The comparison can be to the moderate or heavy congestion value. However, they can not be mixed in any single computation. If the

calculated value is less than the tabulated values, congested operation system wide is slight. A higher travel rate than the tabulated value indicates area wide congestion.

Defining the CMS Network

Designation of the CMS network is a major component in the implementation and administration of a congestion management system. This network forms the area for congestion measuring and monitoring activities and for implementing future congestion management techniques. The CMS network should include freeways and major arterial streets in a manner which will provide network continuity. The CMS network, where applicable, also includes transit and ferry operations which operate over or relate directly to the highway and street network. Where transit operates on separate right-of-way, these routes should also be included.

It is important to designate a complete and useful CMS network. The designated network should have appropriate continuity. Logic would suggest that most major roadways would be included in a CMS network; however, every high volume road or street is not automatically included. Criteria based on volume or VKT (VMT) may be used to help select network components. The National Highway System might be a logical base when identifying a State CMS network.

When selecting a network it should be remembered that each segment identified must be monitored on a regular basis. In addition, the network will be used to help identify roadways and intersections to be evaluated in a land-use impact analysis and to help identify candidate elements to be included in the TIP/STIP.

The modeling network used for forecasting volumes and future congestion needs to have extensive continuity. The modeling network also needs to have a great deal more detail than the designated CMS network. Both the continuity and detail are necessary to achieve realistic link loadings representing the major streets in the modeling process. However, only the major routes will be of interest in the CMS program.

Identification of an extensive CMS network will require collection of a large quantity of data. For these reasons, the network should be defined in a very systematic and objective manner. Such a procedure for defining the CMS network follows.

1. Divide all freeway and arterial roadways in the agency's area of jurisdiction into segments of similar cross section.

2. Assemble the traffic volume data for each segment identified in step 1. Where traffic count data are not available for all network segments, the missing volumes might be developed by interpolating between those locations for which counted volumes are available. In urban areas where a traffic assignment has been made, the link loadings might be used to obtain a traffic volume for each segment.

3. Calculate the vehicle-kilometers (vehicle-miles) of travel on each segment.

4. Array the segments in descending order of VKT (VMT).

5. Determine the total VKT (VMT) on all segments.

6. Sum the VKT's (VMT's) until 70 percent, or some other selected percentage, of the area VMT (vkt) has been reached.

7. Review the resulting system for discontinuities and add links to provide the desired degree of network continuity.

8. For transit routes on separate right-of-way, use steps 1 through 7 to select the transit portion of the CMS network. Person-kilometers (person-miles) rather than vehicle-kilometers (vehicle-miles) should be used.

The resulting network will be objectively selected and representative of the entire metropolitan area. For these reasons, selection of the links to be included in the network will be less subject to local pressures. The CMS network for each urbanized area should be formally adopted by the metropolitan planning organization. Modifications of the network would only be allowed by a vote of the MPO.

Since the CMS must evaluate expected (future) congestion as well as existing congestion, a future network (or networks) also needs to be identified. The traffic volumes on each roadway segment (step 2) for calculation of VKT (VMT), or vkt (step 3) are readily available from the traffic assignment. A simple utility program can be used to perform steps 2 through 6. Where the modeling process is employed by the MPO, it is suggested that the following network loadings be utilized in identifying the CMS.

1. Existing trips on the existing network,
2. Future trips on the existing network,
3. Future trips on the long range plan network(s).

These traffic assignments are routinely done as part of the metropolitan planning process. Hence, they involve little or no additional effort for a CMS.

ISTEA requires that the TIP be a financially constrained, three-year program. It may be logical to assign trips to a network(s) which consist of the existing network plus those elements contained in the TIP. The trip table for this assignment might be obtained by interpolation between the existing trip table and that for the long range plan.

Traffic counts on highways outside of urban areas may not be available for all segments of the State CMS network. However, interpolation between traffic count locations will provide reasonable values for performing steps 2 through 6. Future volumes for use in forecasting expected congestion will likely be obtained from trend analysis or the

extrapolation technique or by analogy. Assigned traffic volumes, similar to those for urban areas, are not a practical option due to the difficulties in developing a reliable trip table.

Monitoring Congestion

The ISTEA clearly states that long term monitoring and projection of congestion on the designated CMS network is expected. The monitoring of congestion must be integrated with the other management systems for efficient data collection and processing. Figure 3-1 suggests the functional relationship of the management systems. Four of the management systems are highly interrelated; the pavement management system and the bridge management system essentially stand alone. The traffic monitoring activity overlaps all six of the management systems. This suggests that to the degree possible, the system definitions for the four interrelated systems should have common boundaries.

It is desirable that the boundary of the air quality district coincide with a TMA boundary to facilitate monitoring and program implementation. However, air quality district may include two or more TMAs or MPOs, or a MPO may include all or part of two or more air quality districts because of geographical conditions. The San Francisco Bay Area is an example of an especially complex region for which common boundaries are impractical since parts of Alameda and Central Costa Counties are in the Bay Area air quality area and parts are in the Central Valley although all of both counties are within the area covered by the Metropolitan Transportation Commission which is the MPO for the Bay Area.

Figure 3-1. Functional Relationship of the Existing Management Systems
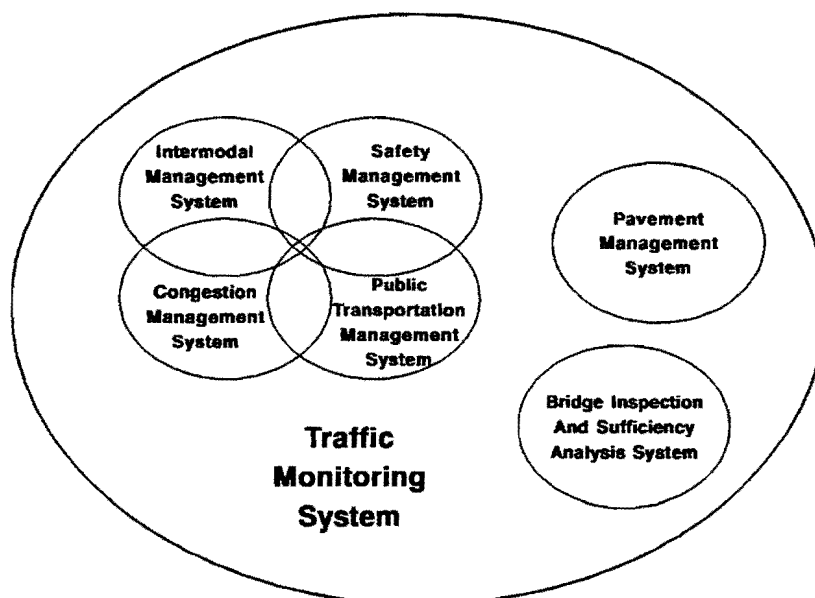
The data collection and monitoring cycle for a CMS should coincide with the frequency with which the CMS is to be updated. Thus, if the CMS is to be updated every two years, data can be collected on a two year program. One-half the data could be collected each year, so as to spread the data collection effort. Or, all the data might be collected in a single year.

It may be desirable to update the CMS each year so that it corresponds to the annual development of the TIP and STIP. However, congestion patterns are rarely likely to change so rapidly that annual monitoring for the CMS will be essential.

The cost of monitoring congestion will depend upon the measure of congestion selected for use as well as the data collection cycle. Travel time related measures typically involve test vehicles driven through the system periodically. The Alameda County experience (5) indicates that travel time studies on the freeway of a moderate size community would involve the commitment of about $15,000 to $20,000 per year. This includes data collection, processing, analysis and reporting costs. Travel time studies on arterial streets appear to be somewhat less costly. The limited data available suggest that a cost in the range of $500 per mile ($315 per kilometer) should be expected for each data collection period.

Automated data collection systems reduce the staff resources necessary to collect the data. However, the initial cost of the automated system is substantial. Based upon Texas Transportation Institute's analysis of the systems being installed in Houston, Dallas-Fort Worth and other cities, typical costs for automated data collection are estimated to be about $74,600 per kilometer ($120,000 per mile) initial cost and $6200 to $7500 per kilometer ($10,000 to $12,000 per mile) annual cost should be expected. This system includes the field hardware at 3.2 kilometers (two mile) intervals on the arterial system and 8 kilometer (five miles) on freeways; the control center and the communications network to transmit the data to the control center. This cost structure assumes that freeway ramp control facilities are in place or will come on line with the automated data collection system and bear a large portion of the total cost of the system.

Data to evaluate the level-of-service for an intersection costs $400 to $600. Assuming that data are collected at 1.6 kilometer (one mile) intervals on arterial streets, the expected cost per kilometer would be $250 to $375 per kilometer ($400 to $600 per mile) for each data collection period. Volume/capacity ratio analysis requires the same data.

Intersection delay is rarely measured directly in the field due to the difficulty in obtaining the data. Most commonly, intersection delay is calculated based upon counted turn movements and the calculated delay is used to establish the LOS. Delay estimates for roadway segments are normally taken with the travel time data mentioned above.

While many measures of congestion are possible, travel rate (minutes per mile or minutes per kilometer) is probably the most appropriate for a CMS. It applies equally to transit, ferries and auto modes, if the one accounts properly for the access times for each

mode. As the travel rate increases, the system is becoming more congested. For these reasons travel rate is the recommended measure of congestion. The reader is reminded that monitoring costs are continuous. Any effort in the planning stages that will save money on the data collection will pay off many times in the coming years.

Transportation Planning Models

Transportation planning models have become more user friendly and widely distributed at the local government level in recent years. The fundamental concept on which these models operate are, however, still basically long range planning oriented. Peak period volumes are normally based on a percentage of the ADT that is expected during the peak period. This estimation could be substantially in error. Errors in the input data are known to have a significant impact on the traffic assignment. Also, local governmental units often do not have personnel with a sufficient working knowledge of the planning model to properly interpret the output from the model. Moreover, there is a need to develop a model that is more suitable for modelling all types of trips, especially pedestrian and bicycle trips in addition to the automobile, transit and ridesharing trips.

Recent studies of the ability of the transportation planning model commonly used nationally to reproduce the turning movements at intersections, given the peak period inputs to a very detailed network were notably unsuccessful in producing individual turn movement volumes which reproduce ground counts. However, this modeling technique produces better approach volumes than the present capacity restraint procedure. This means that the projection of demand from a planning model for the purpose of estimating future intersection LOS has little chance of being successful. The turning movements and the subnetwork external station input flows were actual counted flow rates recorded in fifteen minute intervals. Studies many years ago proved that a more detailed network does not improve the quality of the modelling output when using the conventional capacity restraint procedure. The number of trips across a screen line may be reasonably accurate, yet the individual links within the network may be 100% or more in error. Higher volume links are commonly estimated more reliably than lower volume links. This accounts for the fact that corridor travel times tend to be reasonably accurately estimated.

Transportation planning models can produce travel time estimates for individual travel corridors with a fair degree of reliability. For this reason among others, travel rate has been recommended as the basic measure of congestion. The planning models can then be used to project the future level of congestion.

RECOMMENDATIONS

The following recommendations and suggestions are based on a synthesis of the interviews, documents prepared for or by various agencies, and groups on measuring congestion. These recommendations should be considered in the development and

implementation of a CMS Program in response to the ISTEA. Some of the recommendations are controversial; some may not be compatible with current local or state requirements or practices. In general, the implementation of the CMS program should establish the goals and objectives to be achieved and give the local governmental unit a maximum of flexibility in achieving that goal.

1. Travel rate (minutes per kilometer) should be encouraged but not required as the method of measuring and defining congestion. If the State or local governmental unit selects another measure of congestion, they should be required to demonstrate how that measure can be integrated into an area wide measure of congestion.

2. The CMS subnetwork for surface transportation should be defined through the use of vehicle-kilometer (vehicle-mile) of travel on the system. A suggested criteria for urban areas is that the CMS network should include those route segments which account for at least 70 percent of the travel (VKT or VMT) in the region. In rural areas, at least all routes on the National Highway System should be included in the State CMS. All freeway links and fixed guideway transit links should be included.

3. The CMS network should be formally adopted by the designated CMS agency and changes in the designated system should be allowed only by a two-third majority vote of the representatives of the political subdivision within the CMS area.

4. The monitoring system for congestion should, as a minimum, require reevaluation of all freeway links and links which were previously identified as being congested or are approaching congestion. Congested or approaching congestion based on an average operating speed which is twenty five kilometers per hour (15 mph) below the posted speed might be defined by a travel rate such as given in Table 3-3.

5. Links in the CMS system should be reviewed on an appropriate cycle. In most urban areas a two or three year cycle should be adequate for monitoring congestion. Inspections might include situations where large scale development or employment changes have occurred or where extremely rapid urbanization is occurring.

**Table 3-3: Travel Rate Defining Congested
Or Near Congested Conditions By Roadway Type**

Freeways	0.8 minutes/kilometer (1.3 minutes/mile) or more during the peak period.
Arterials	45 mph - 1.3 minutes/kilometer (2.0 minutes/mile) or more during the peak period. 40 mph - 1.5 minutes/kilometer (2.4 minutes/mile) or more during the peak period. 35 mph - 1.9 minutes/kilometer (3.0 minutes/mile) or more during the peak period. 30 mph - 2.6 minutes/kilometer (4.0 minutes/mile) or more during the peak period.

6. Data for CMS monitoring should not be collected where congestion may be affected by maintenance or short term construction.

7. A management system should not involve a large or bulky report. It is suggested that an annual report no more than five single spaced type written pages detailing the status of congestion in the metropolitan area be required. One page should be a succinct summary of the congestion in the metropolitan area. The second and third pages should contain the interpretation of the meaning of the congestion measure written in layman's language. These pages should address the cost of congestion to the motoring public, a listing of the more important deficiencies on the CMS system and a very brief statement of the approach suggested to addressing the deficiencies identified. Pages four and five should contain the necessary data to allow a comparison of congestion with other metropolitan areas nationally. The report should be submitted through normal channels in hard copy and faxed directly to a central repository for collation into a national congestion impacts report and permanent storage.

This report is not intended to detail the studies or to evaluate the approaches taken to address congestion deficiencies. It is intended as an annual status report of the state of congestion in the CMS area.

8. The goals oriented approach being used in the State of New York is suggested as a model for CMS programs. The State of New York has implemented a goal oriented approach to transportation management. This process essentially follows the Systems Engineering methodology of 1) Establishing the goal(s); 2) Setting the objectives to be accomplished that will achieve the goal(s); and 3) Developing specific tasks (projects) to execute that will satisfy the objectives. This approach deserves careful consideration by state and local transportation agencies.

9. The CMS Structure should have one responsible agency in each metropolitan area. The exception is when the area is so large that one agency cannot practically manage that scope of work. In this latter case, more than one responsible agency for subareas of the metropolitan area should be allowed. The responsible CMS agency should be the designated metropolitan planning agency. Where two or more responsible CMS agencies are identified in one metropolitan area, all local governmental units on the boundary between the two should be a full member of both to insure coordination across the boundary.

    The potential for a CMS program that is less than fully successful exists in every metropolitan area. Divided responsibilities and allegiances will naturally lead to a wide diversity of opinion on the "best" approach to solving a problem. If each of the political subdivisions in a metropolitan area are allowed to make independent decisions, the transportation system in the metropolitan area will never be optimal for the metropolitan area as a whole. The focus of the planning effort is the designated planning agency or MPO. The designated CMS agency must have sufficient authority to ensure that decisions are in the best interest of the entire metropolitan area.

    Unfortunately, experience indicates that the personality of the Director of the designated planning agency is the single most important factor in the MPO success or lack of success. The ability to work with the local governmental units while insisting that all decisions be in the best interest of the entire metropolitan area requires a high level of political ability and the ultimate in committee direction. While the risk is great that the selected person will not have the required skills, even if the skills are present, the lack of adequate authority will ensure poor decision making.

10. All units of government should be encouraged to develop access control plans for major roadways as a CMS strategy. Elements of such a plan should include the following:

    1) Signalized intersections at a minimum spacing of one-half mile (804 meters). Placement of additional signals within these limits after the roadway is opened to traffic should result in the local governmental unit forfeiting the Federal funds expended in the construction or reconstruction of the roadway.

    2) Nontraversable median between signalized intersections.

    3) Not more than two median opening between signalized intersections. These openings must be designed to prevent direct crossing of the arterial roadway and have acceleration and deceleration lanes to minimize the impact of entering traffic on the arterial street operation.

4) A driveway ordinance that restricts the number of unsignalized intersections (public streets and private driveways) entering the arterial to an absolute minimum. Any private driveway carrying less than 100 vehicles per day shall have right-turn in and right-turn out access only. All private driveways must be designed with deceleration space. Either parallel or taper designs may be used. They permit the arterial street traffic to decelerate without creating more than a 16 km/hr (10 mph) speed differential in the through traffic lane.

5) The local governmental unit may choose to not limit right side access on arterial streets by paying the entire cost of the facility in excess of the access controlled roadway which is necessary to achieve an equivalent capacity and travel rate. The medial access must not be compromised in this process. Failure to satisfy the nontraversable median requirement should disqualify any proposed project for Federal funding.

The topic of access control on arterial roadways is fully developed in Appendix C. It suffices here to point out that an arterial street developed with the access control principles described above have a 30%-50% higher capacity and 50% to 60% fewer accidents than the same street without incorporating these design principles. In reducing future congestion on the system, it is imperative that arterial street access be carefully controlled in new designs and in all occupancy change decisions for developed property.

11. The air quality agency(s) in the CMS area should be a full member of the CMS Policy Committee but not have veto over the decisions made by the Policy Committee. Clearly all decisions must comply with environmental law. It is the relative position of the air quality agency that is of concern. They must be willing to negotiate in a meaningful manner in the best interest of the community as a whole.

The quality of the environment is paramount to all persons involved in the transportation industry. The southern California interviewees focused on the air quality issue to a high degree. The air quality people were typically portrayed as having very narrow view of the metropolitan area's problems and refusing to consider the perspective of the other involved parties. Recommendation 9 is not intended to decrease the emphasis on environmental quality in any way. The intent is to point out that the environmental decisions are not made in isolation. Rather, they are made in a complex of economic, social and political realities that must all be fully considered and the decision made that is in the best interest of the residents of the entire metropolitan area.

12. The Environmental Impact Master Agreement idea should be carefully considered for CMS project administration. Under this concept, a general agreement would be reached by all concerned agencies on the environmental goals and objectives of the metropolitan area. Individual CMS Projects could then be approved with a simple declaration of compatibility with the approved Environmental Master Agreement.

13. Implementation of the CMS program must recognize the practical limitation of the percentage of ridesharing within one business. Average vehicle occupancy values that require more than 30% ridesharing are very costly to achieve and unstable. That is, the conversion to ridesharing tends to be temporary. These expenditures are not productive in our economic system and the instability results in the expenditure not achieving the environmental goal as well.

14. CMS strategies should focus more on providing incentives to meet trip reduction requirements rather than penalizing businesses for a failure to reach target values.

15. Local governments should be encouraged to adopt an ordinance that details the mitigation fees to be charged for traffic impacts of new development. A fee schedule should be established based on the expected impact that a development will have on congestion. The advantage of a uniform mitigation fee is that the developer knows the costs of development, regardless of its timing within the development cycle. Also every developer pays the same fee for a given size of development. All share in the congestion mitigation effort rather than one paying the lion's share of the cost and another paying little.

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APPENDIX A

SITE VISIT SCHEDULE AND PRINCIPAL CONTACTS

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Table A-1. Site Visit Schedule

Agency	City	Contact	Site Visit Date & Time
Contra Costa County CMA Bay Area Transportation Commission Alameda County CMA CALTRANS - District 4 Santa Clara County CMA San Joaquin County Trans. Commission	Walnut Crk, CA San Francisco Hayward, CA Oakland, CA San Jose, CA Stockton, CA	Robert McCleary Hank Dittmar Dennis Fay Paul Hensley Michael Evanhoe Andy Chesley	2/16 - 8:30 am 2/16 - 2:00 pm 2/17 - 8:30 am 2/18 - 9:00 am 2/18 - 4:30 pm 2/19 - 9:00 am
Los Angeles County Met. Trans. Authority Southern CA Association of Governments Riverside County Trans. Commission CALTRANS - District 11 San Diego Transportation Mgmt Assoc. San Diego Association of Governments	Los Angeles, CA Los Angeles, CA Riverside, CA San Diego, CA San Diego, CA San Diego, CA	Brad McAllester Robert Huddy Paul Blackwelder Stuart Harvey Amy Perkins Kenneth Sulzer	3/8 - 9:00 am 3/8 - 1:30 pm 3/9 - 9:00 am 3/10 - 8:00 am 3/10 - 3:00 pm 3/11 - 9:00 am
Bi-State Regional Commission St. Cloud Area Planning Organization Chicago Area Transportation Study	Rock Island, IL St. Cloud, MN Chicago, IL	Denise Bulat Bill Hansen Gerald Rowling	3/22 - 9:00 am 3/23 - 2:00 pm 3/24 - 8:30 am
Washington Department of Transportation Puget Sound Regional Council	Olympia, WA Seattle, WA	Toby Rickman Bob Sicko	4/19 - 10:00 am 4/19 - 2:00 pm
Capital District Transportation Committee New York Department of Transportation	Albany, NY Albany, NY	John Poorman Clarence Fosdick	4/19 - 8:30 am 4/19 - 1:00 pm
North Carolina Department of Trans. Charlotte Department of Transportation	Raleigh, NC Charlotte, NC	Ron Poole Bill Finger	5/14 - 9:30 am 5/15 - 9:30 am
Pima Association of Governments Pikes Peak Council of Governments Colorado Department of Transportation Denver Regional Council of Governments	Tucson, AZ Colorado Springs Denver, CO Denver, CO	James Altenstadter John Hanlon Bill Stringfellow Steve Rudy	6/8 - 8:30 am 6/9 - 9:00 am 6/9 - 1:00 pm 6/10 - 2:00 pm
Southwest WA Regional Trans. Council	Vancouver, WA	Dean Lookingbill Robert Hart	6/28 - 3:00 pm 6/29 - 1:30 pm

Alameda County Congestion Management Agency

Site Visit Date and Time: February 17, 1993 @ 8:30 AM
Principal Contact: Dennis Fay, Executive Director
                           24301 Southland Drive, Suite 200
                           Hayward, CA 94545-1541
                           510-836-2560
                           FAX: 510-785-4861
Interviewers: Vergil G. Stover, Texas Transportation Institute
                           Ron Giguere, Federal Highway Administration
Others in Attendance: None

Bay Area Metropolitan Transportation Commission
Site Visit Date and Time: February 16, 1993 @ 2:00 PM
Principal Contact: Hank Dittmar, Manager of Legislation and Finance
                           101 Eighth Street
                           Oakland, CA 94607-4700
                           510-464-7810
                           FAX: 510-464-7848
Interviewers: Vergil G. Stover, Texas Transportation Institute
                           Ron Giguere, Federal Highway Administration
Others in Attendance: Charles L. Purvis, Senior Transportation Planner/Analyst
                           Therese Watkins McMillan, Senior Planner
                           Karen Fink, Transportation Planner/Analyst

Bi-State Regional Commission
Site Visit Date and Time: March 22, 1993 @ 9:00 am
Principal Contact: Denise Bulat, Direct. of Transportation & Environmental
                           Services
                           P.O. Box 3368
                           Rock Island, IL 61204-3368
                           309-793-6300
                           FAX: 309-373-6305
Interviewer: Dr. Vergil Stover, Texas Transportation Institute
Others in Attendance: Gena Standaert, Planner
                           Patrick J. Weidemann, Planner

California Department of Transportation, District 4
Site Visit Date and Time: February 18, 1993 @ 9:00 AM
Principal Contact: Paul Hensley, Deputy District Director
                               111 Grand Avenue
                               Oakland, CA 94612
                               510-286-5900
                               FAX: 510-286-6301
Interviewers: Vergil G. Stover, Texas Transportation Institute
                               Ron Giguere, Federal Highway Administration
Others in Attendance: H. "Aki" Morimoto, Branch Chief
                               James S. McCrank, Chief, Traffic Systems Branch
                               William R. Schott, Chief, Highway Operations

California Department of Transportation, District 11
Site Visit Date and Time: March 10, 1993 @ 8:00am
Principal Contact: Stuart H. Harvey, Deputy District Engineer
                               P.O. Box 85406
                               San Diego, CA 92186-5406
                               619-696-5210
                               FAX: 619-688-6648
Interviewer: Donald L. Woods, Texas Transportation Institute
Others in Attendance: Mr. Fred Yazdan, Chief, Traffic Operations Branch

Capital District Transportation Committee
Site Visit Date and Time: April 19, 1993 @ 8:30 AM
Principal Contact: John Poorman, Staff Director
                               5 Computer Drive West
                               Albany, NY 12205
                               518-458-2161
                               FAX: 518-459-2155
Interviewer: Vergil G. Stover, Texas Transportation Institute
Others in Attendance: David P. Jukins, Principal Transportation Engineer

Charlotte Department of Transportation
Site Visit Date and Time: May 15, 1993 @ 9:30 AM
Principal Contact: Bill Finger, Assistant Director
600 E. Fourth Street
Charlotte, NC 28202-2858
704-336-3900
FAX: 704-336-3497
Interviewers: Vergil G. Stover, Texas Transportation Institute
Brian Hoeft, Federal Highway Administration
Others in Attendance: None

Chicago Area Transportation Study
Site Visit Date and Time: March 24, 1993 @ 8:30 AM
Principal Contact: F. Gerald Rawling, Director of Operations Analysis
300 West Adam Street
Chicago, IL 60606
312-793-3467
FAX: 312-793-3481
Interviewer: Vergil G. Stover, Texas Transportation Institute
Others in Attendance: Andrew V. Plummer, Deputy Director
Kermit W. Wies, Director of Plan Implementation
Ed J. Christopher, Director of Systems Surveillance
Patricia Berry, Director of Community Liaison
Other Agencies: Regional Transportation Authority:
Ronald A. Shimizu, Manager of Planning Division
Northeast Illinois Planning Commission:
Elisa C. Hoekwater, Transportation/Land Use Planner

Colorado Department of Transportation
Site Visit Date and Time: June 9, 1993 @ 1:00 PM
Principal Contact: Bill Stringfellow, Manager, Transportation Planning Business
Group
4201 E. Arkansas, Room 225
Denver, CO 80222
303-757-9757
FAX: 303-757-9727
Interviewer: Vergil G. Stover, Texas Transportation Institute
Others in Attendance: None

Contra Costa Transportation Authority

Site Visit Date and Time:	February 16, 1993 @ 8:30 AM
Principal Contact:	Robert K. McCleary, Executive Director
	1340 Treat Blvd., Suite 150
	Walnut Creek, CA 94596
	510-938-3970
	FAX: 510-938-3993
Interviewers:	Vergil G. Stover, Texas Transportation Institute
	Ron Giguere, Federal Highway Administration
Others in Attendance:	Marin R. Engelmann, Deputy Director, Planning

Denver Regional Council of Governments

Site Visit Date and Time:	June 10, 1993 @ 2:00 PM
Principal Contact:	Steve Rudy, Manager, Mobility Management Program
	2480 West 26th Avenue, Suite 200B
	Denver, CO 80211
	303-480-6747
	FAX: 303-480-6790
Interviewer:	Vergil G. Stover, Texas Transportation Institute
Others in Attendance:	None

Los Angeles County Metropolitan Transportation Authority

Site Visit Date and Time:	March 8, 1993 @ 9:00am
Principal Contact:	Brad McAllester, Executive Director
	818 West 7th Street, 4th Floor
	Los Angeles, CA, 90017
	213-244-6590
	FAX: 213-244-6025
Interviewer:	Donald L. Woods, Texas Transportation Institute
Others in Attendance:	Edwark K. Shikada, Highway Program Manager, CMP
	Edric F. Guise, Private Sector Liaison for LACTC

New York Department of Transportation

Site Visit Date and Time: April 19, 1993 @ 1:00 PM
Principal Contact: Clarence Fosdick, Director, Systems and Program Planning
Bureau
1220 Washington Avenue
Albany, NY 12232
518-457-7055
FAX: 518-457-4944
Interviewer: Vergil G. Stover, Texas Transportation Institute
Others in Attendance: Jeffrey Trombly, Systems and Program Planning Bureau

North Carolina Department of Transportation

Site Visit Date and Time: May 14, 1993 @ 9:30 AM
Principal Contact: Ron Poole, Statewide Planning Branch Manager
P.O. Box 25201
Raleigh, NC 27611
919-733-4705
FAX: 919-733-2417
Interviewers: Vergil G. Stover, Texas Transportation Institute
Brian Hoeft, Federal Highway Administration
Others in Attendance: Roberto Canales, Traffic Control Engineer
Mike Bruff
Lieda Huffsinger
David Hider
Other Agencies: FHWA, North Carolina District Office:
Lorrie Coe

Pikes Peak Council of Governments

Site Visit Date and Time: June 9, 1993 @ 9:00 AM
Principal Contact: John Hanlon, Transportation Director
15 South Seventh
Colorado Springs, CO 80905
719-471-7080
FAX: 719-471-1226
Interviewer: Vergil G. Stover, Texas Transportation Institute
Others in Attendance: None

Pima Association of Governments

Site Visit Date and Time:	June 8, 1993 @ 8:30 AM
Principal Contact:	James Altenstadter, Director, Transportation Planning Division
	100 North Stone Avenue, Suite 1100
	Tucson, AZ 85701-1517
	602-628-5313
	FAX: 602-628-5315
Interviewer:	Vergil G. Stover, Texas Transportation Institute
Others in Attendance:	Karen Morehouse, Transportation Planning Division
	Dave Wolfson, Transportation Planning Division

Puget Sound Regional Council

Site Visit Date and Time:	April 19, 1993 @ 2:00 PM
Principal Contact:	Robert T. Sicko, Principal Planner
	216 First Avenue South
	Seattle, WA 98104
	206-464-5325
	FAX: 206-587-4825
Interviewer:	Donald L. Woods, Texas Transportation Institute
Others in Attendance:	Larry Dlain
	Bill Roach
	Nick Roach

Riverside County Transportation Commission

Site Visit Date and Time:	March 9, 1993 @ 9:00 AM
Principal Contact:	Paul Blackwelder, Deputy Director
	3560 University Avenue, Suite 100
	Riverside, CA 92510
	909-787-7141
	FAX: 909-787-7920
Interviewer:	Donald L. Woods, Texas Transportation Institute
Others in Attendance:	None

San Diego Association of Governments

Site Visit Date and Time: March 11, 1993 @ 9:00 AM
Principal Contact: Kenneth Sulzer, Executive Director
                          401-B Street, Suite 800
                          San Diego, CA 92101
                          619-595-5300
                          FAX: 619-595-5305
Interviewer: Donald L. Woods, Texas Transportation Institute
Others in Attendance: Lee Hultgren, Director of Transportation
                          Mr. Plummer, Traffic Engineering Services
                          Mr. Hicks, Transportation Planning

San Diego Transportation Management Association

Site Visit Date and Time: March 10, 1993 @ 3:00 PM
Principal Contact: Amy Perkins, Executive Director
                          625 Broadway, Suite 1020
                          San Diego, CA 92101
                          619-696-5210
                          FAX: 619-237-0673
Interviewer: Donald L. Woods, Texas Transportation Institute
Others in Attendance: None

San Joaquin County Council of Governments

Site Visit Date and Time: February 19, 1993 @ 9:00 AM
Principal Contact: Andy Chesely, Executive Director
                          P.O. Box 1010
                          Stockton, CA 95201-1010
                          209-468-3913
                          FAX: 209-468-1084
Interviewers: Vergil G. Stover, Texas Transportation Institute
                          Ron Giguere, Federal Highway Administration
Others in Attendance: Stephen VanDenburgh, Associate Regional Planner

Santa Clara County Congestion Management Agency

Site Visit Date and Time:	February 18, 1993 @ 4:30 PM
Principal Contact:	Michael P. Evanhoe, Executive Director
	101 Metro Drive, Suite 248
	San Jose, CA 95110
	408-453-4030
	FAX: 408-453-4145
Interviewers:	Vergil G. Stover, Texas Transportation Institute
	Ron Giguere, Federal Highway Administration
Others in Attendance:	Andrew Nash
	Jerry Goldberg, Consultant to Santa Clara County

Southern California Association of Governments

Site Visit Date and Time:	March 8, 1993 @ 1:30 PM
Principal Contact:	Robert H. Huddy, Senior Transportation Planner
	818 West 7th Street, 12th Floor
	Los Angeles, CA 90017
	213-236-1800
	FAX: 213-236-1963
Interviewer:	Donald L. Woods, Texas Transportation Institute
Others in Attendance:	Debra A. Varnado, CMS Program Chief
	Ralph Apriani

Southwest Washington Regional Transportation Council

Site Visit Date and Time:	June 28, 1993 @ 3:00 PM & June 29, 1993 @ 1:00 PM
Principal Contact:	Dean Lookingbill, Transportation Director
	1351 Officers' Row
	Vancouver, WA 98661
	206-737-6067
	FAX: 206-696-1847
Interviewer:	Vergil G. Stover, Texas Transportation Institute
Others in Attendance:	Robert W. Hart, Senior Transportation Planner

St. Cloud Area Planning Organization
Site Visit Date and Time: March 23, 1993 @ 2:30 PM
Principal Contact: William Hansen, Executive Director
                          665 Franklin Avenue N.E.
                          St. Cloud, MN 56301
                          612-252-7568
                          FAX: 612-251-3499
Interviewer: Vergil G. Stover, Texas Transportation Institute
Others in Attendance: Doran Cote, Traffic Engineer
                          David Finn, Traffic Technician

Washington State Department of Transportation
Site Visit Date and Time: April 19, 1993 @ 10:00 AM
Principal Contact: Toby Rickman, Manager, District & Regional Planning Branch
                          P.O. Box 47370
                          Olympia, WA 98504-7370
                          206-705-7967
                          FAX: 206-705-6813
Interviewer: Donald L. Woods, Texas Transportation Institute
Others in Attendance: Loyd R. Fergestrom, Transportation Systems Engineer
                          Brian Ziegler, Systems Planning Branch Manager

APPENDIX B

METHODS FOR DEFINING AND MEASURING CONGESTION

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Introduction

The Interim Final Rule for the Congestion Management System (7, §500.503) defines congestion as:

> "...the level at which transportation system perfor-
> mance is no longer acceptable due to traffic
> interference. The level of acceptable system
> performance may vary by type of transportation
> facility, geographic location (metropolitan area or
> subarea, rural area) and/or time of day."

A Congestion Management System (CMS) involves a systematic process to measure transportation system performance, forecast potential congestion, and evaluate alternative congestion mitigation strategies. In order to accomplish this, an appropriate variable to measure congestion must be selected. For what ever performance measure (quality of traffic flow) that is selected, a value which constitutes unacceptable congestion must be selected. The Interim Final Rule gives States and MPOs broad latitude in selecting both the performance measure and the magnitude of this variable which constitutes congestion.

This appendix identifies and evaluates the various measures of the quality of traffic flow that might be considered for use in a CMS. The measurement definitions will include the type of raw data needed for the measure and the methods available to collect it. The measures are evaluated on their effectiveness on spot, corridor, and subarea/area wide levels in terms and ease of implementing, collecting, and recording. Each measure is also evaluated as to its ease of forecasting future congestion. The various measures of quality of flow that might be considered for use in a CMS are identified in Table B-1.

Any technique chosen by a CMS to measure congestion should be broad enough to include all forms of surface transportation, i.e. trucks, buses, as well as private autos. In doing this, the measure needs to focus on overall mobility rather than vehicle movement. Where truck traffic and bus volumes are significant, the quantity of people and products moved is more valuable than the total number of vehicles.

The selected measure of congestion for use in a CMS must be applicable as a corridor and areawide measure. Many of the measures to be defined within this Appendix are spot measures of congestion. To apply these spot measures along an entire corridor or over an entire area, the measure must be assumed to transfer over sections of roadway.

Table B-1. Potential Measures of Roadway Congestion

Performance Effectiveness	Application			Ability to Forecast Congestion
	Spot	Corridor	Areawide	
Level of Service	X			
Lane-kilometers of LOS "X"		X	X	
VKT of LOS "X"		X	X	
Average Travel Speed		X		
Spot Speed	X			
Average Travel Time		X		X
Average Travel Rate		X	X	X
Travel Time Contours			X	X
Total Delay	X			
Excess Delay	X	X	X	
Average Delay per Vehicle/Person	X			
Delay/Incident	X			
Delay/VKT				
Delay/Trip		X		
Delay due to Construction	X	X		
Volume, Flow Rate	X			
Volume/Capacity Ratio	X			
Midblock V/C Ratio	X			
Volume/"Acceptable Flow Rate"	X	X	X	X
Suggested Congestion Index		X	X	
Roadway Congestion Index		X	X	
Minute-kilometers of Delay				
Detector Occupancy	X			
Queue Length and Duration	X			
Acceleration Noise	X			
Accident Rates	X	X	X	
Percent VKT By Functional Class		X	X	
VMT/Lane-kilometer		X	X	
Persons/Hour	X	X	X	X
Persons/Vehicle	X	X	X	
ODOT Level of Capacity	X	X	X	X

1 km/h = 0.6 mph
1 km = 0.6 miles

It is possible to obtain a system wide measure from many of the congestion measurement values along a segment of a facility by weighing the measure according to the vehicle-kilometers (veh-miles) of travel (VKT (VMT)) along that segment. Two elements are required to calculate a system wide measurement. The congestion measure to be used must be quantitative (i.e., travel rate, travel speed, and volume/capacity ratios), and the measure to be weighted must be applicable over a length of roadway. The system wide congestion measure is obtained through the use of the following equation:

$$System\ Wide\ Congestion\ Measure = \frac{\sum M_i L_i T_i}{\sum L_i T_i}$$

Where

M_i = quantitative congestion measurement along section i,
L_i = length of section i (miles or kilometers),
T_i = ADT in section i.

The weighing of measures allows comparison between facilities with differing volumes, lengths, and functional classes.

The urban transportation modeling process provides forecasted values for some of the suggested congestion measures. Through the process, link volumes, travel times, and speeds are obtainable for current and future conditions in an urban environment. A shortcoming of the urban transportation modeling process is that the duration of speeds is not given, for example, less than 35 miles (55 kilometers) per hour for 15 minutes or longer. And, there is no similar reliable model for statewide application.

Level of Service

The most common measure currently used to define congestion involves Level-of-Service (LOS) values as defined in the *1985 Highway Capacity Manual* (HCM) (3) or in some cases Circular 212. LOS is a qualitative measure describing operational conditions of a segment or traffic stream. Six different levels are defined (LOS A, B, C, D, E, and F) with LOS A representing the best condition and LOS F representing the worst condition. LOS can be defined and measured differently depending upon the roadway facility it is describing. A definition of congestion involving LOS values is common, with many agencies indicating either LOS E or F as congestion. However, because of the various methods of determining LOS, these values are usually not comparable between roadway classifications.

For signalized intersections, LOS is defined in terms of average stopped delay per vehicle for a 15-minute analysis period. Stopped delay is dependent on a number of variables, including the quality of progression, the cycle length, the green ratio, and the v/c ratio for the approach. An analysis of stopped delay requires turning movement counts at

the intersection under investigation. Turning movement counts are labor intensive and therefore expensive to conduct. Measuring congestion using stopped delay is not recommended. LOS values for signalized intersections are shown in Table B-2. Intersection LOS is a spot measure of congestion.

Table B-2. LOS Criteria for Signalized Intersections

Level of Service	A	B	C	D	E	F
Stopped Delay Per Vehicle (sec)	≤ 5.0	5.1 to 15.0	15.1 to 25.0	25.1 to 40.0	40.1 to 60.0	> 60.0

SOURCE: Reference (3)

For arterial streets, LOS is based on average travel speed for the segment, section, or entire arterial under consideration. Average travel speed is determined from the running time on the arterial segment and the intersection approach delay. LOS criteria for urban and suburban arterials is shown in Table B-3.

Table B-3. LOS Criteria for Urban and Suburban Arterials

Arterial Class	Range of Free Flow Speeds km/h (mph)	Typical Free Flow Speed km/h (mph)	Level of Service					
			A	B	C	D	E	F
I	56 to 72 (35 to 45)	64 (40)	≥ 56 (35)	≥ 28 (45)	≥ 22 (35)	≥ 17 (27)	≥ 13 (21)	< 13 (21)
II	48 to 56 (30 to 35)	53 (33)	≥ 48 (30)	≥ 24 (39)	≥ 18 (29)	≥ 14 (23)	≥ 10 (16)	< 10 (16)
III	40 to 56 (25 to 35)	43 (27)	≥ 40 (25)	≥ 19 (31)	≥ 13 (21)	≥ 9 (14)	≥ 7 (11)	< 7 (11)

SOURCE: Reference (3)   1 km/h = 0.6 mph

The HCM classifies freeway LOS based upon vehicular densities (passenger cars per mile per lane). Table B-4 shows LOS criteria for basic freeway sections.

Table B-4. LOS Criteria for Basic Freeway Sections

Level of Service	Maximum Density
A	7 pc/km/ln
B	12 pc/km/ln
C	19 pc/km/ln
D	26 pc/km/ln
E	42 pc/km/ln
F	> 42 pc/km/ln

Source: Reference (3)   1 km = 0.62 miles

NCHRP Report 7-13 (2) found that only 2 percent of the agencies surveyed use density as a measure of congestion. Due to the ease of data collection and the relationship between density and the v/c ratio, v/c ratios are often used in the LOS analysis.(2)

Public officials have come to recognize LOS as a measure of traffic flow. They do not always know how LOS is obtained or implemented, but the lettering system (i.e., LOS "D") appeals to them for its simplicity. Without understanding any of the technical computations or jargon behind the lettering system, public officials are able to compare past and present traffic conditions on a given roadway section using LOS as the primary performance measure.

LOS was developed and is predominantly used as an operational tool. The term operational implies the meaning real time analysis (i.e., today). However, CMSs need a measure that is capable of estimating future congestion. From the state-of-the-practice review, it was found that people working in operations generally favor using LOS as a measure of congestion. The state-of-the-practice review also found that, outside of operations, there were relatively few individuals who had tried LOS and wanted to continue to do so.

Intersection LOS is based on the average stopped delay per vehicle, derived from turning movement counts. At present, there are no procedures to forecast turning movements. Average travel speeds, the LOS criteria for arterials, are obtained as a point measure, and then extrapolated over a section of roadway. As with turning movement counts and travel speeds, vehicular densities cannot be used to forecast future congestion. Thus, LOS has significant shortcomings for use as the performance measure in a CMS.

Lane-kilometers of LOS "X"

Lane-kilometers (ln-mi) of LOS "X" incorporates LOS (qualitative) values into a quantitative measure of congestion. Once the LOS designations are assigned along a facility, the lane-kilometers (ln-mi) of roadway sections operating at or below LOS "X" are tabulated and reported. Lane-kilometers (la-mi) of LOS "X" can be used to measure congestion for corridor or areawide applications.

The difficulties in forecasting lane-kilometers (ln-mi) of LOS "X" are the same as those encountered in forecasting intersection and freeway LOS.

Vehicle-Kilometers of Travel (VKT) at LOS "X"

Vehicle-kilometers (Veh-Mi) of travel (VKT (VMT)) at LOS "X" uses the same rationality as lane-kilometers at LOS "X". The VKT of all roadway sections operating at or below LOS "X" are totaled and used as a measure of congestion. As with the lane-miles measure, VKT of LOS "X" is applicable on a corridor or areawide basis. However, since the measure is based on LOS values, the use of VKT of LOS "X" as the performance measure for a CMS is limited by LOS's inherent weaknesses (the inability to project turning counts, vehicular speeds, or vehicular densities).

Average Travel Speed

The average travel speed is computed as the distance travelled divided by the average total time to traverse a given highway segment. It is obtained from a travel time study along the route. The total time includes stopped delays in addition to the actual time of motion; and the necessary number of travel time runs depends on the variance in travel time, the acceptable degree of precision, and the level of confidence desired. As discussed for the LOS criteria of arterials, travel speeds cannot be forecasted. Therefore average travel speeds are a poor measure of congestion.

Average travel speed is a space mean speed (SpMS).

Average Spot Speed

Spot speed, or time mean speed (TiMS), is defined as the average speed of all vehicles passing a point on a highway over some specified time period. Spot speed can only be used to measure congestion as a spot application.

The following example highlights the differences between TiMS and SpMS.

In lane 1, vehicles are spaced at 26.82 m (88 ft) and are travelling at 13.41 m/s (44 fps). In lane 2, vehicles are spaced at 53.64 m (176 ft) and are travelling at 26.82 m/s (88 fps).

Therefore, vehicles in either lane will pass a stationary point every 2.0 seconds. In calculating the TiMS, there would be equal numbers of vehicles travelling at 13.41 m/s (44 fps) and 26.82 m/s (88 fps).

$$TiMS = \frac{13 + 27}{2} = 20 \ m/s$$

In calculating SpMS, a given length of the highway must be considered. Assuming complete uniformity of the traffic stream, lane 1 contains twice as many vehicles as lane 2. Therefore, the average speed of vehicles occupying a given length -- SpMS -- includes twice as many vehicles travelling at 13.41 m/s (44 fps) as at 26.82 m/s (88 fps), and the space mean speed is:

$$SpMS = \frac{2(13) + 27}{3} = 17.7 \ m/s$$

Slower vehicles are weighed more heavily in space mean speed calculations, as they occupy space in the given segment of roadway for a longer period.

Average spot speed is not considered to be a good performance measure for use in a CMS for the following two reasons:

1)   It is very difficult, if not impossible, to forecast; and
2)   It is not suitable as a corridor or areawide measure.

Average Travel Time

The average travel time is defined as the total time to traverse a length of roadway under prevailing traffic conditions. All stopped delays are included in the average travel time. The average travel time measure can be used to compare the quality of service of various alternate routes from point of origin to point of destination.

There are a number of techniques currently used or being studied to collect travel time data. A partial listing includes:

- Test-car techniques: 1) Floating-car method or 2) Average-car method,
- License-plate matching technique,
- Photographic technique,
- Interview technique,
- Cellular telephone reporting,
- Automatic vehicle detection systems,
- Global positioning systems.

Travel time estimation methodologies are further investigated in Appendix L. Using the current travel times measured or generated by these techniques, computer models are able to forecast future travel times.

Unless the travel times are measured in short increments of length between an origin and a destination ("O" and "D"), the times are only a measure of congestion from point "O" to point "D". This makes it impossible to use travel times as an areawide measure of congestion. As with average travel speeds, average travel time is most easily used as a measure of congestion along route segments. A corridor or areawide measure can be obtained by weighing the travel time on each segment by the VKT (VMT) of that segment.

Average Travel Rate

This measure is the average time, generally in minutes, required to travel a prescribed distance (one kilometer or one mile) along a route or through a system of routes. Average travel rate is the reciprocal of average travel speed, and is generally reported in minutes per kilometer (per mile). Average travel rate can measure congestion on both a corridor and subarea/area wide level.

Any of the methods used to collect travel time data can be employed to measure the average travel rate. The average travel rate can be used to compute or estimate travel time along routes, or through a system of routes. It works well as a measure of the effectiveness of individual routes or a network of streets. Average travel rate can be applied to compare routes and it also serves as an indication as to the effectiveness of traffic control devices and other control measures in a system.

The average travel rate was selected as the most applicable measure of congestion when the possible uses (i.e., congestion measurement, corridor analysis, and air quality monitoring) and users (air quality board, government officials, the general public, developers, and commuters) of congestion information were analyzed. The users wanted the congestion measure to be something usable and easily understood -- travel rates satisfy these demands.

The urban transportation modeling process can be used to forecast average travel rates. The greatest flow rate achievable along roadway facilities occurs at a speed of just under 64.4 k/h (40 miles/hour) or at an average travel rate of 0.98 minutes/km (1.58 minutes/mile).

Travel Time Contours

Travel time contours utilize average travel times to illustrate travel times from one location to numerous destinations. This information is graphically transposed onto a map which shows the area that can be reached in 5-minute intervals. Travel time contour maps have limited applications since only one origin location is studied at a time. Urban travel time contours can be forecasted since the modelling process can be used to develop the basic travel time information which is needed. However, their one origin at a time only applicability limits their usage as a measure of congestion for use in a CMS.

Total Delay

Total delay, or stopped delay, is the time which a vehicle is stopped in traffic or at an intersection. Expressed in seconds per vehicle, stopped delay can be measured as the actual "locked wheel" time, or in terms of time, less than a very slow speed, such as 8km/h (5 mph). The HCM's delay equation uses turning movement volumes to capacity ratios to determine stopped delays at intersections. Intersection delay is not a good performance measure for use in a CMS for the following two reasons:

1) The inability to forecast turning movements of an intersection, and
2) It is not readily adaptable as a corridor or areawide measure.

However, delay studies are useful for determining the locations, causes and lengths of delays. Total delay information can only be used to locate and measure spot areas of congestion.

Excess Delay

Excess delay is the actual or projected travel time in excess of the travel time which is considered to be acceptable based upon an average overall speed. The travel times are obtained from the urban transportation modelling process. Excess delay is therefore, a planning measure, rather than an operational measure. Excess delay along a corridor, or subarea, can be calculated by summing estimates of excess delay on each section of roadway.

Excess delay can be used as a multimodal congestion measure. Each mode (automobile, freight, transit, or bicycle) is measured using varying thresholds of excess delay. Excess delay can be implemented as a spot, corridor, or areawide congestion measure. Since average travel time can be forecast using the urban transportation modelling process, excess delay can also be forecast.

Average Delay per Vehicle per Person

Average delay per vehicle per person combines two congestion measures -- total average delay and persons per vehicle. The combined measure works well in that it measures congestion in terms of individuals. However, since average delay per vehicle per person also depends on intersection turn volumes in its calculation, it cannot be accurately forecasted. Secondly, it also requires the forecast of vehicle occupancy for each turn movement; and there is no reliable means of projecting this variable. And thirdly, it is a spot measure of congestion.

Delay per Trip

Delay per trip is the travel time delay per trip, where travel time delay is defined as the difference between the time a vehicle traverses a length of roadway and the time it would have done so if it had traversed the length of roadway at the desired speed without stopping, and where a trip is defined as a length of roadway between two points of interest. Based on travel times, the delay per trip measure can be projected using computer models. The measure is applicable as a corridor measure of congestion.

Delay per Vehicle-Kilometer (Vehicle-Mile) of Travel

Delay per vehicle-miles (kilometers) of travel is a measure of congestion for roadway segments which is comparable to the average delay per vehicle used for intersections. It can be calculated as:

$$Delay\ per\ VKT\ (VMT) = \frac{D(\frac{V}{60})}{VL}$$

Where:
D = Calculated Average Delay per Vehicle
V/60 = Volume on the Roadway Segment in Vehicles per hour divided by 60 minutes per hour
V = Volume on the Roadway Segment in Vehicles per hour
L = Length of the Roadway Segment in kilometers (miles)

This measure of delay eliminates total vehicle delay in a manner which considers the length of the roadway segment. Thus, it permits a direct comparison of congestion on various roadway segments which are of different lengths.

Minutes-Kilometers (Min-Miles) of Delay

Minute-kilometers (or minute-miles) delay is the product of the length of a roadway segment and the difference between an acceptable travel rate and the actual travel ratio which can be calculated by the following formula:

$$MKD = \sum_{i=1}^{n} [L_i\ (DTR_i - ATR_i)(V)]$$

Where
MKD = Minute-kilometers delay (MMD = Minute-miles delay),
L = Length of the roadway segment in kilometers, or miles,
DTR_i = Desired travel rate in segment i,
ATR_i = Actual travel rate in segment i,
V = Traffic volume on segment i for a selected time period (peak hour or peak period),
n = Number of roadway segments,
ATR_i = 60 minutes/Speed on segment i in km/h or mph.

This measurement of congestion could be used where ever travel speed can be observed and forecast. However, the concept of minute-kilometers (vehicle-miles) delay is not easily understood and interpretation of it is difficult to communicate to nontechnical people. Therefore, it is recommended that it not be used as the performance measure for a CMS.

Delay Due to Construction

Delay due to construction measures the delay at spot locations or along corridors under construction. The delay is measured in terms of the difference between the free flow travel time and the actual travel time of vehicles along the route.

Delay per Incident

Delay per incident is the total stopped delay which occurs during incidents such as accidents. Since the incidents are random and site specific, delay per incident can only measure spot congestion. It is an inadequate measure of the quality of traffic operations along a corridor or over an entire area.

Volume, Flow Rate

The rate of flow is a measured or forecasted traffic demand. The rate of flow, or actual volume, on a roadway section can be determined by counting the vehicles that pass over the roadway section during a specified time period. The vehicle count should be qualified by the composition of traffic.

The rate of flow does not specify how well a facility is operating. Any given flow rate, less than capacity, can occur under conditions of high density and low speed or low density and high speed. However, flow rate is the primary parameter used by traffic engineers in all design and analysis methodologies.

Due to the fact that volumes are variable along roadway segments, they are only used as a spot measure of congestion. Computer models have proven to be inaccurate when generating future volumes or flow rates. Therefore, using volumes or flow rates to forecast future congestion is unreliable and ill-advised.

Intersection Volume/Capacity Ratio

$$v/c = \frac{rate \ of \ flow}{capacity}$$

The intersection volume/capacity (v/c) ratio is defined as the ratio of actual volume or rate of flow at an intersection to the capacity of the intersection. The actual volume is determined as described above for rate of flow. The measure is often broken down into the v/c ratio of individual turn movements. This requires turning movement volumes at the intersection. The capacity of a roadway is the maximum flow rate achievable through the intersection per lane or roadway in one direction. This maximum flow rate is obtained from the prevailing traffic, roadway, and control conditions. Depending on the type of facility, these conditions may include, but are not limited to: area type, lane and shoulder width, grades, adjacent parking, heavy vehicles, bus blockage, right turns, left turns, access control, cycle length, signal phasing, and progression speed.

The individual road user has little realization of the volume level itself, but rather the driver is aware of the effect of high volume on his ability to travel on a given facility with reasonable speed, comfort, and safety. For a facility to provide an acceptable quality of traffic operations requires that the rate of flow be substantially lower than the capacity of the roadway.

Due to the fact that the capacity of a facility varies with the prevailing conditions at a particular intersection, the intersection v/c measure is site dependent, and is best used as a spot measure of congestion.

Intersection v/c ratios are not good performance measures for use in a CMS for the following two reasons:

1)   The inability to forecast turning movements of an intersection, and
2)   It is not readily adaptable as a corridor or areawide measure.

Most agencies obtain the volumes for the intersection v/c measure by conducting turning movement counts at the intersections in question. The collection and reduction of turning movement volumes is a time consuming and expensive procedure. Cities such as Charlotte, North Carolina and Tucson, Arizona have real time data collection systems installed on much of their street networks. Data are collected automatically at intersections on the network, and adding new intersections to an existing network is relatively easy and inexpensive. However, the initial cost of implementing these collection systems is expensive.

Midblock Volume/Capacity Ratio

Midblock volume/capacity ratios are based on the volumes and capacities at a midblock location along a given segment of roadway. An argument against midblock v/c ratios is that intersections, not midblock cross sections, control the capacity of a roadway, and therefore most delays experienced along a given roadway segment will also occur at the intersections, not at a midblock location. Therefore, although midblock v/c ratios have the ability to measure congestion, the ratios are less informative than other congestion measures.

Roadway Congestion Index

The roadway congestion index (RCI) employs daily vehicle-kilometers (vehicle-miles) of travel (DVKT (DVMT)) per lane-kilometer (lane-mile) of roadway for both freeways and principal arterial streets within an empirically derived formula. The RCI equation weights the DVKT (DVMT) per lane-kilometer (lane-mile) values for the two functional classes by its respective amount of DVKT (DVMT), which is then normalized by DVKT (DVMT) per lane-kilometer (lane-mile) representing the threshold of congestion (LOS D or worse).

$$RCI = \frac{[\frac{FVKT \ (or \ FVMT)}{Ln-Km \ (Mile)} + \frac{AVKT \ (or \ AVMT)}{Ln-Km(Mile)}]}{[13,000xFVKT \ (or \ FVMT) + 5,000xAVKT \ (or \ AVMT)]}$$

Where
FVKT = Freeway Vehicle-kilometers of travel (FVMT = Freeway Vehicle-miles of travel),
AVKT = Arterial street vehicle-kilometers (vehicle-miles) of travel,
13,000 = Areawide average of threshold daily VKT (VMT) for freeways
  5,000 = Areawide average of threshold daily VKT (VMT) for arterials

Note: The threshold values are based on maintaining speeds above 65 km/h (40 mph) and 50 km/h (30 mph) for freeways and arterials, respectively.

A normalized RCI value greater than 1.0 indicates that congested conditions exist on an areawide basis.(2) Urban areas with RCI values less than 1.0 may have congested roadway sections, but the average mobility level within the area is uncongested as defined by the RCI.

Volume/"Acceptable Flow Rate"

The capacity is not always the best datum for determining the level of congestion along a given section of roadway. The driver's perception of congestion often relies more on an "acceptable flow rate", than on the actual capacity of the roadway. The acceptable flow rate is the flow rate which the local jurisdiction judges to be acceptable and is based on such factors as the number of lanes, access control, signalized intersection spacing, intersection design, traffic control, etc..

Volume/acceptable flow rate is an appropriate measure of existing congestion when there is little transit present.

The Volume/"Acceptable Flow Rate" can measure congestion along roadway segments. To be applicable on a corridor level of analysis, the roadway segments can be weighted according to the VKT (VMT) within the corridor. Once weighted, the measure becomes the Suggested Congestion Index, discussed in the next section.

Suggested Congestion Index

The Roadway Congestion Index, defined previously, is a system wide measure of congestion on the street and freeway system. Its disadvantage is it only applies to the surface street and highway mode of travel. Since travel rate (minutes per mile or kilometers per mile) is a more generic measure that applies equally well to all modes of transport the RCI must be converted to be compatible with travel rate.

A method of accomplishing this is:

$$ SCI = \frac{\sum \textit{Travel rate x VKT (VMT) for all travel modes}}{X_1 FVKT\ (FVMT)\ +\ X_2 AVKT\ (AVMT)} $$

Where

VKT (VMT)	= Vehicle-kilometers (vehicle-miles) of travel
FVKT (FVMT)	= Freeway Vehicle-kilometers (vehicle-miles) of travel
AVKT (AVMT)	= Arterial Street Vehicle-miles (-kilometers) of travel
X_1, X_2	= Variables based on roadway classification

NOTES: 1)   The sum of each segment's travel rate multiplied by its corresponding VMT (vkt) is implied by the numerator. The denominator is the approximate composite congestion level indicator.

               2)   Person-kilometers (person-miles) of travel may be substituted for VKT (VMT) in the equation when occupancy values are available.

The Suggested Congestion Index is an extension of the Volume/"Acceptable Flow Rate" measure. The Volume/"Acceptable Flow Rate" is weighted using VMT (vkt) to provide for the measurement of congestion on a corridor and areawide level. The SCI is also much like the midblock v/c ratio measure.

Intersection Level of Capacity

Intersection level of capacity was developed by the Oregon Department of Transportation to quantify the extent of acceptable reserve capacity at intersections. The measure is actually the critical v/c for the entire intersection. This v/c is composed of the major conflicting lane groups. The critical v/c was chosen to define the status (reserve capacity) of an intersection -- delay, commonly used to measure the level of service at an intersection, cannot define the reserve capacity.

Given the nature of the measure, it can only measure congestion at spot locations (signalized intersections). Intersection level of service measures congestion at spot locations in much the same way that volume/"acceptable flow rate" measures corridor congestion.

Detector Occupancy

Detector occupancy is the ratio of the time that vehicles are present at a detection station in a traffic lane compared to the total time of sampling. This measure of congestion is limited to jurisdictions where a large sophisticated traffic surveillance and control system is in place.

Detector occupancy measurements can be converted into a measure of minute-miles of congestion. This measure is defined as the product of congested miles and congestion duration on individual freeway segments.

Detector occupancy is a spot measure of congestion. Although well understood by transportation technicians, detector occupancy is often confusing to the general public. Measuring occupancy rates requires a freeway and/or arterial detector network. Detector occupancy cannot be readily used to forecast future conditions.

Detector occupancy data are frequently obtained from inductance loop detectors imbedded in the pavement of the roadway. The reliability of the detector data is directly related to the amount of time spent maintaining and tuning the detectors. If tuned daily, the reliability of the data is 98%. This value drops to around 95% when the detectors are tuned only periodically; and if the detectors are not maintained, the reliability is only 65% after a period of about six months. Thus, the credibility of the percentage detector accuracy is no better than an educated guess on the occupancy. Without investing in the maintenance, the reliability of data obtained is not worth the initial investment of installing the detector system.

Queue Length and Duration

Queue length and duration can be determined through direct observation. Parameters such as maximum and average number of vehicles in the queue can be computed. Aerial photography techniques can be used to determine queue length and duration at specific locations. There are computer models which estimate queue and duration, but they are sensitive to input values. The general public can relate the concept of queues to congestion due to the back-up of traffic experienced by drivers.

Queue length and duration are site dependent and therefore are used as spot measures of congestion. Forecasting congestion based on queue length and duration is not practical because there is no reliable method of accurately predicting either queue length or duration.

Acceleration Noise

Acceleration noise is measured along roadway facilities using the floating car method. The acceleration noise is calculated as a function of number, duration, and rate of the floating cars' accelerations. The idea behind the measure is that as congestion increases, vehicles are forced to decelerate and accelerate repeatedly. The noise measured during acceleration is louder than the noise of free flowing traffic. Knowing this, acceleration noise can be used to measure existing congestion. There is no accurate way of forecasting acceleration noise. Each year the characteristics of vehicles change slightly; and with the implementation of alternative fuels and engines, it is unknown as to the noises these vehicle's will output during free flow or congested conditions. Another problem with acceleration noise is its inability to be used as a multimodal measure -- rail systems could not be included in a corridor or areawide measurement.

Accident Rates

The number of accidents per million vehicles entering a spot location or the number of accidents per million vehicle-kilometers (vehicle-miles) over a section of roadway can be used as an indicator of congestion. The nature of accidents, and the way they are recorded, make it difficult to measure congestion from accident rates alone. At very high traffic volumes when there is a bottleneck of traffic and the inability to change lanes, there may also be a reduction in friction between vehicles and a corresponding reduction in accidents. There is also a wide variance in the reporting of accident data by local law enforcement agencies. Two major problems are that not all accidents are reported and that the exact accident location is not identified. Accident rates are applicable as spot, corridor, and areawide measures. Accident rates alone are not a suitable measure of congestion.

Percent Vehicle-Kilometers (Vehicle-Miles) of Travel by Functional Class

The percent vehicle-kilometers (vehicle-miles) of travel (VKT(VMT)) by functional class measures the kilometers (miles) travelled on each classification of roadway. This is useful information when investigating the usage of roads within a region, but it cannot identify congestion or the quality of traffic flow along a facility. It is not a practical measure of congestion.

Vehicle-Kilometers (Vehicle-Miles) of Travel per Lane-Kilometer (Lane-Mile)

The vehicle-kilometers (vehicle-miles) of travel per lane-kilometer (lane-mile) is an indicator of service volume or demand. A large VKT (VMT) per lane kilometer (mile) may indicate the facility is congested for one or more hours per day. However, VKT (VMT) per lane kilometer (lane-mile) is essentially a function of density along a roadway facility and the relationship between rate of flow and density is nonlinear. Flow rates less than capacity may occur under two conditions: 1) high speed and low density, and 2) low speed and high density. Therefore, unless speed data are used to supplement VKT/lane-kilometer (VMT/ lane-mile), the quality of service along the facility is not known.

Persons per Hour or Vehicles per Hour

Persons per hour and vehicles per hour are simply a measure of throughput (i.e. volume at a point on a roadway segment or across an imaginary lane intercepting 2 or more routes in a corridor or through an intersection). They differ only in that persons per hour is applicable to carpooling and transit.

In order to be a meaningful measure of congestion some acceptable conditions to the number of persons, or vehicles, which constitute acceptable levels of congestion must be determined. Therefore, it is not suitable for measuring congestion.

Persons per Vehicle

Persons per vehicle gives no indication as to the level of congestion or as to the quality of flow on a facility. When used in conjunction with other measures descriptive of the flow of traffic, persons/vehicle becomes an acceptable measure of congestion. Persons per vehicle is beneficial because it quantifies the total number of persons, rather than mere vehicles, being transported.

Oregon DOT Level-Of-Capacity Procedure

The Oregon Department of Transportation (ODOT) uses a V/C ratio in analyzing signalized intersections. While the ODOT procedure is similar to the intersection V/C ratio previously discussed, it merits separate explanation for at least the following two reasons: 1) a different critical volume is used and 2) the method of interpreting the V/C ratio differs.

The ODOT procedure is not used to tune and coordinate signalized intersections. The purpose in using the V/C ratios is to determine if the signals can be properly timed and coordinated in response to different possible conditions. Thus, the Oregon DOT procedure is a "planning technique" where the LOS procedure in the HCM and Circular 212 are techniques to assess the "operational efficiency" for a given set of conditions.

The following reflect some of the differences between the Oregon DOT planning procedure and the HCM operational approaches. Chapter 9 of the HCM states that intersection delay is not directly related to V/C. This is true. The HCM further states that an intersection with a low V/C value, with an inefficiently timed signal, can have high delay, and an intersection with a high V/C (0.95-1.0), with an efficiently timed signal, can have low delay. Again, this is true. However, it is also true that an efficiently timed traffic signal with a low V/C value will usually have less delay than it would otherwise have if it had a high V/C value, due to shorter cycle lengths and phasing used.

Delay, and hence the LOS in the HCM, does not provide information on how much reserve capacity may be remaining at an intersection (or a weighted average of the delays at several intersections along a corridor or in a subarea). The Oregon DOT procedure provides a measure of reserve capacity. Further, the Oregon DOT procedure is simpler and requires less information than the HCM Chapter 9 procedure. Both of these considerations are significant in a CMS because congestion must be both monitored and projected. Utilization of the ODOT procedure, or some other simplified V/C method, is particularly appropriate in that future turn volumes can not be projected with any degree of reliability. Operational procedures such as HCM are appropriately applied when timing or retiming signals in response to the specific traffic volumes pertaining to one point in time.

When selecting a V/C ratio or saturation level which represents unacceptable congestion, it should be recognized that traffic volumes fluctuate from cycle to cycle and that an intersection V/C ratio will exceed the estimated or projected value for a number of cycles. For example, if the estimated V/C is 0.90, the actual V/C for one or more cycles may exceed 0.95. Operation may "break down" very quickly and recovery will be difficult, especially in coordinated signal systems.

SIGCAP is a computer program to evaluate the intersection reserve capacity using the Oregon DOT procedure. The theory used in the development of SIGCAP tries to account for the fact that traffic conditions in a smaller area may be interpreted as being a worse level of service than the same conditions in a larger area. This concept assumes that drivers from each area are willing to tolerate different degrees of congestion. Level of

service can be defined by a sliding scale. The part of the scale to use depends on the metropolitan size. The maximum capacity level (EF), however, is the same for all areas.

ODOT relates the saturation value (V/C) to a level of capacity as follows:

Table B-5. ODOT Saturation V/C Values

Metro Size and Saturation Value				
More than 500,000	100,000 to 500,000	20,000 to 100,000	Less Than 20,000	Level of Capacity
.00-.55	.00-.52	.00-.50	.00-.48	A
.56-.66	.53-.64	.51-.61	.49-.59	B
.67-.75	.65-.73	.62-.71	.60-.69	C
.76-.79	.74-.77	.72-.75	.70-.73	C-D
.80-.86	.78-.85	.76-.84	.74-.83	D
.87-.90	.86-.89	.85-.88	.84-.87	D-E
.91-.97	.90-.97	.89-.97	.88-.97	E
.98-1.01	.98-1.01	.98-1.01	.98-1.01	E-F
1.02+	1.02+	1.02+	1.02+	F

The saturation value (level of saturation) is the ratio of the green time required to the green time available plus the ratio of the amber time to the cycle time:

$$\text{Saturation Value} = \frac{VG}{Sg} + \frac{A}{C}$$

Where

V = Volume on the approach (vehicles per hour),
G = Total green time for the entire cycle (seconds),
S = Saturation or capacity flow rate, i.e., the maximum number of vehicles, that could pass with green during the whole hour (vehicles per hour),
g = The effective movement green time available (seconds),
A = The total amber time for the entire cycle (seconds),
C = The total cycle length (seconds).

ODOT has developed a microcomputer software package (SIGCAP) to perform the calculations for signalized intersections. Another package (UNSIG) has been developed for unsignalized intersections.

SUMMARY

A number of variables are available as potential measures of congestion. The following need to be considered when selecting a measure of congestion for use in an effective congestion management system.

1)   It must be suitable to corridor and areawide/subarea applica-
       tions in quantifying congestion.
2)   One must be able to forecast the variables used in calculating
       the level of congestion as well as obtain the data for calculation
       of current congestion.
3)   The variable(s) used should be easy to obtain for measuring
       existing as well as forecasted congestion.
4)   The measure of congestion should be easily understood by the general public.
5)   It should be a multimodal mobility measure, not just a highway measure,
       where transit is, or may be, a significant mode of travel and/or where truck
       traffic is an important issue.

Of the potential measures of congestion, average travel rate and volume/"acceptable flow rate" are considered to be the most appropriate measures for use in a CMS. Travel rate can be used as a multimodal mobility measure including autos and transit as well as goods movement. Travel rates can be forecast in the urban transportation planning process.

Volume/"acceptable flow" rate is highway based and is a suitable measure of congestion where transit is not a significant issue. It is conceptually easy to understand and an advantage is that the acceptable flow rate is similar to the "capacity" used in the urban transportation modeling process.

In areas where numerous signalized intersections are present, intersection level of capacity is effective in measuring congestion at spot locations.

APPENDIX B REFERENCES

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3. *1985 Highway Capacity Manual (HCM)*, Special Report 209, Transportation Research Board, National Research Council, 1985.

4. *Measures of the Quality of Traffic Service*, Special Report 130, Highway Research Board, National Research Council, 1972.

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APPENDIX C

ACCESS MANAGEMENT AS A
CONGESTION MANAGEMENT STRATEGY

Appendix C is a reproduction in its entirety of the paper prepared for the First National Conference on Access Management held in Vail, Colorado, August 1-4, 1993. It is reproduced in this Appendix due to the importance of access management in both short term and long term congestion management programs.

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OVERVIEW

It is now recognized that the construction of additional lanes on existing arterials and new roadways cannot fully alleviate current or future congestion. In response to the need to conserve investment in transportation infrastructure, the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) mandated the development and implementation of six management systems (traffic congestion, safety, public transportation, intermodal, pavement, and bridges).

Access control is an effective method for managing congestion and is a necessary part of a congestion management system (CMS). Access management techniques include signal coordination, signal spacing, the use of non-traversable medians, the spacing of median openings, the design of unsignalized medial access to prohibit crossings and limit left-turns, the location and design of driveway and intersection spacing, the provision of deceleration lanes for turning traffic, and interparcel circulation. All of these methods are effective in improving traffic flow and reducing congestion on arterial streets.

For example, increasing the signalized intersection spacing to uniform intervals of one-half mile and the use of a non-traversable median to restrict left-turns will increase the capacity of a four-lane urban arterial by about 50% as compared to quarter-mile signal spacing and unrestricted left-turns. This is the same increase in capacity that can be obtained by widening a four-lane divided arterial to six lanes. Also, safety will be increased and congestion reduced to a greater extent than by the roadway widening.

Fewer but better designed driveways reduce the conflict between turning and through traffic which translates to reduced congestion. It also increases the capacity for traffic to enter the arterial street from adjacent properties. And, interparcel circulation reduces congestion by removing trips from the public street system.

INTRODUCTION

Congestion can be defined as the condition where traffic on streets or highways ceases to operate at an acceptable level of service -- speeds diminish and drivers experience delays. Congestion increases vehicle-hours of delay, wastes fuel, and increases vehicular emissions. Roadways operating at or above acceptable capacity are the primary cause of congestion. Capacities can be increased to accommodate the traffic demand by the construction of additional lanes and/or by imposing congestion management measures which enhance the flow of traffic along the arterial.

As part of the Intermodal Surface Transportation Efficiency Act (ISTEA) all states are required to develop and implement Congestion Management Systems (CMSs) to identify, measure and monitor congestion as well as to address the sources of congestion. Effective administration of a CMS can be used to: 1) manage or reduce the existing congestion; and 2) avoid future congestion problems from occurring.

In the past, the primary measures used to reduce congestion have been the construction of new roadways or the reconstruction of existing streets. However, on highly congested roadway sections, reconstruction alone cannot fully alleviate congestion. In response to the growth in congestion and mounting environmental regulations -- most notably the Clean Air Act of 1990 -- transportation agencies are looking at alternatives that utilize existing arterial streets. Access management techniques are often used in conjunction with roadway reconstruction projects to manage and minimize congestion.

For over thirty years the interstate system has been a testament to the benefits of access control. No other system of roadways uses the high level of access control found on the interstates; and consequently, no other system operates as efficiently. Improved capacity can also be achieved on major arterial streets with the implementation of access controls. In the construction or reconstruction of arterial roadways, some degree of access control needs to be designed for -- particularly new facilities where the potential for commercial or office development exists.

The 1984 and 1990 editions of *A Policy on the Design of Geometric Highways and Streets* promote functional design rather than the previously followed volume-based design. "The failure to recognize and accommodate by suitable design each of the different trip stages of the movement hierarchy is a prominent cause of highway obsolescence." (1 p.2; 2 p.2) The functional design of streets utilizes the principle that individual elements of a street system do not serve travel independently, and that each element of a functional hierarchy serves as a collecting/distributing facility for the next higher element of the system. This hierarchal street system provides for the graduation in function from access to movement. Effective street design also recognizes that there is a hierarchy of intersections which provide the transition (connection) between roadways in a hierarchal system. (34) Congestion and conflicts occur along major arterials when the transitions are either misplaced or functionally inadequate. Control of access to an arterial will reduce

interference between turning and through traffic, promote movement, and consequently minimize congestion.

Access management relies on a variety of access control techniques to promote efficient vehicular movements. (4,24) These include the following:

- Limit Number of Conflict Points.
- Separate Conflict Points.
- Limit Deceleration.
- Remove Turning Vehicles from Through Lanes.
- Space major intersections to facilitate progressive travel speeds along arterials.
- Provide adequate on-site storage to accommodate both ingress and egress traffic.

Several access management techniques implement all of the above categories in one measure. Of these techniques, signal coordination and spacing, medial access treatment, and marginal access treatment (driveway spacing) will be discussed due to their significance and proven proficiency in congestion management.

An added benefit of effective access management along major arterials is the improvement in fuel efficiency. The fuel consumption rate per mile is reduced by improving the quality of vehicular traffic flow.(28) Decreasing the number of stops, starts, and their respective accelerations and decelerations improves a vehicle's fuel efficiency. Studies conducted by the Texas Transportation Institute (29) documented the fuel savings as a result of access control measures. The study compared an arterial with half-mile signal spacings and right turns only to an arterial with quarter-mile signal spacings and allowing left and right turns. The arterials considered had the following conditions and results:

Conditions:
- Ten-mile section of urban arterial
- 700 vehicles per hour per lane in peak direction
- 55-45 directional split
- Two-hour morning and two-hour evening peak periods
- Speed of 13 mph (20 km/h) without access control, 22 mph (35 km/h) with access control

Fuel Savings:

Improvements in speed	240,000 gal/yr
Reduction in delay	335,000 gal/yr
	575,000 gal/yr

Access management maximizes steady, uncongested, and safe traffic flows while still allowing access to abutting property. Implementing access management on existing and new major roadways, as a part of a congestion management system, improves traffic operations

as a whole along arterials. Effective access management also improves traffic safety. The number of conflict points, and therefore accidents, are reduced by careful management of the access points granted along an arterial. Therefore, the ranking of all potential access points according to their functional hierarchy is imperative. In this paper, access management as a congestion management tool is organized in the following categories.

        1)   Signalized intersection spacing and coordination
        2)   Medial access treatment
        3)   Marginal access treatment

Signalized intersection spacing has a major impact on the efficient movement of traffic on an arterial. Moreover, an early definition of intersection locations, which will be signalized, has a major influence on land use patterns and on the development of a supporting street system which accommodates short trips. Also, it is disruptive to activity patterns and politically difficult to change signal locations after development has occurred. Thus, signal spacing is perhaps the first factor to consider in the design of a street system on which congestion management is to be exercised.

Medial access is also critical to effective congestion management as well as safety management since a non-traversable median is the only positive means of limiting left-turn ingress and egress movements. The friction between traffic using direct access drives and through traffic further contributes to congestion.

SIGNAL COORDINATION AND SIGNALIZED INTERSECTION SPACING

Introduction

During the planning, design, and operation stages of a signalized arterial street system four variables need to be considered (3):

1) Speed of the Progression Platoon
2) Signal Cycle Length
3) Signal Spacing
4) Efficiency of Progression

Maximum flow rates occur at a uniform speed of approximately 35 mph (55 km/h) to 40 mph (65 km/h). To accommodate peak hour traffic volumes, the arterial needs to operate within this range of speeds. In addition to capacity considerations, vehicle emissions and fuel consumption are also minimized when speeds range between 35 (55 km/h) and 40 mph (65 km/h). However, during off peak operation, a higher range of progression speeds is desired. On major arterials, this desired range of speeds is 45 mph (70 km/h) to 55 mph (90 km/h). Therefore, to accommodate both peak and off-peak traffic demands, it is necessary that the signal timing plan maximize efficient traffic flow for a range of speeds.(4)

Major arterial streets must be able to operate efficiently under a range of combinations of speeds vs. cycle lengths in order to accommodate traffic volumes as they change over time.(3) During off peak hours, a short cycle length is desirable so as to minimize delay; a cycle of about 60 seconds is frequently appropriate. The large volumes present during the peak hours require long cycle lengths to minimize lost time per phase and therefore reduce the overall delay of the intersection. This lost time results from perception-reaction time at the beginning of the green indication, as well as lost times due to excessive headways between queued cars prior to achieving the minimum headway. 120 seconds is generally accepted as the maximum desirable cycle.

The final variable involved in the planning, design, and operation of signalized arterial street systems is the efficiency of traffic progression (progression band width divided by cycle length). As a consequence of increasing the efficiency, capacities increase and delays decrease. A reduction in stopped and delayed vehicles has a direct impact on lowering speed variance, reducing vehicle emissions, and lowering fuel consumption.(3) The effects of these reductions are obviously beneficial to both the environment and congestion management.

Signal Coordination

One of the easiest methods to improve flow and relieve congestion on major arterial streets is to coordinate traffic signals. Traffic signal synchronization projects consist of retiming existing signals, installing advanced computer control, and/or optimizing traffic signal timing plans. The estimated daily impact of implementing a traffic signal synchronization plan is a 10% decrease in vehicle-hours of travel. ([28](#)) Reducing vehicle hours of travel by 10% yields a 3.5% savings in fuel consumption, which amounts to almost 12-million gallons annually for a city with a population of one million. ([28](#))

From 1983 to 1985, the Fuel Efficient Traffic Signal Management Program (FETSIM), a statewide program in California, involved the retiming on 3,172 traffic signals. Significant benefits included first-year reductions of 15% in delays, 8.6% in fuel use, 16% in stops, and 7.2% in travel time. ([36,37](#))

A similar traffic signal synchronization program in Texas resulted in a 24.6% reduction in delay, a 9.1% reduction in fuel consumption, and a 14.2% reduction in stops. ([38](#)) The project required the retiming of 2,243 signals in 44 cities throughout the state. Another synchronization project in Florida yielded similar results with a 13% to 22% reduction in travel time. ([39](#))

Benefit/cost ratios were estimated for many projects and included fuel savings, travel time savings, and vehicle stops eliminated. The National Signal Timing Optimization Project initiated by FHWA in 1981 involved signal timing projects in eleven cities across the United States. The benefit/cost ratios for these projects ranged from 20 to 1 to 30 to 1. ([40](#)) A benefit/cost ratio for a signal optimization project in North Carolina and for the Texas Traffic Light Synchronization (TLS) project were determined to be 108 to 1 and 62 to 1, respectively. ([41,38](#)) These ratios differ substantially due to different estimates on the dollar value of stops, delays, travel time, and fuel. Regardless of the dollar estimate, all of these signal timing projects resulted in a substantial benefit/cost ratio for vehicle stops, travel time, and fuel savings. Since traffic signal synchronization projects are so cost effective and result in substantial benefits, they have proven to be a productive method for reducing delays and congestion on major arterial streets.

Signal Spacing

While traffic signal synchronization methods work well on established arterial street systems, the ideal method of traffic signal access control is to control signal spacing. An arterial street must be able to function efficiently in both peak and off-peak periods. The high volumes experienced during the morning and evening peaks require maximization of the lost time due to changes in signal phases and achievement of high flow rates. Maximum flow rates are obtainable at about 55 km/h (35 mph) or slightly higher speeds. Flow rate decreases markedly at speeds less than 48 km/h (30 mph). A cycle of 120 seconds is commonly considered to the longest cycle length desirable for general use. However, the

signal system must also be flexible so as to provide efficient traffic progression during the off-peak hours when higher speeds and shorter cycle lengths are encountered.

Figure C-1 (3) shows the relationship between signal spacing, speed, and cycle length. Similar information is given in tabular form in Table C-1. A signal spacing of 0.8 km (1/2 mile) produces maximum progression efficiency with a cycle length of 120 seconds and a speed of 48 km/h (30 mph). This spacing also provides for efficient progression with cycle lengths commonly used in off-peak hours (60 to 80 seconds). Inspection of Figure C-1 also shows that progression speed and efficiency will deteriorate with a cycle length larger than 120 seconds. The figure also shows that with 0.402 km (1/4 mile) spacings and peak period cycle lengths (90 seconds or longer), progression speed is much lower than that at which maximum throughput and fuel efficiency occurs. Moreover, a 0.402 km (1/4 mile) signal spacing does not provide flexibility for efficient traffic progression during off-peak periods.

**Table C-1. Optimal[1] Cycle Lengths
for Various Speeds and Signal Spacings (3).**

Speed km/h(mph)	Signal Spacings		
	0.402 km (1/4-mile)	0.536 km (1/3-mile)	0.804 km (1/2-mile)
24(15)	120 sec		
32(20)	90 sec	120 sec	
40(25)	72 sec	96 sec	
48(30)	60 sec	80 sec	120 sec
56(35)	51 sec	69 sec	103 sec
64(40)	45 sec	60 sec	89 sec
72(45)		53 sec	80 sec
80(50)		48 sec	72 sec
88(55)			65 sec
97(60)			60 sec

[1] Maximum progression efficiency   1km/h = 0.6 mph
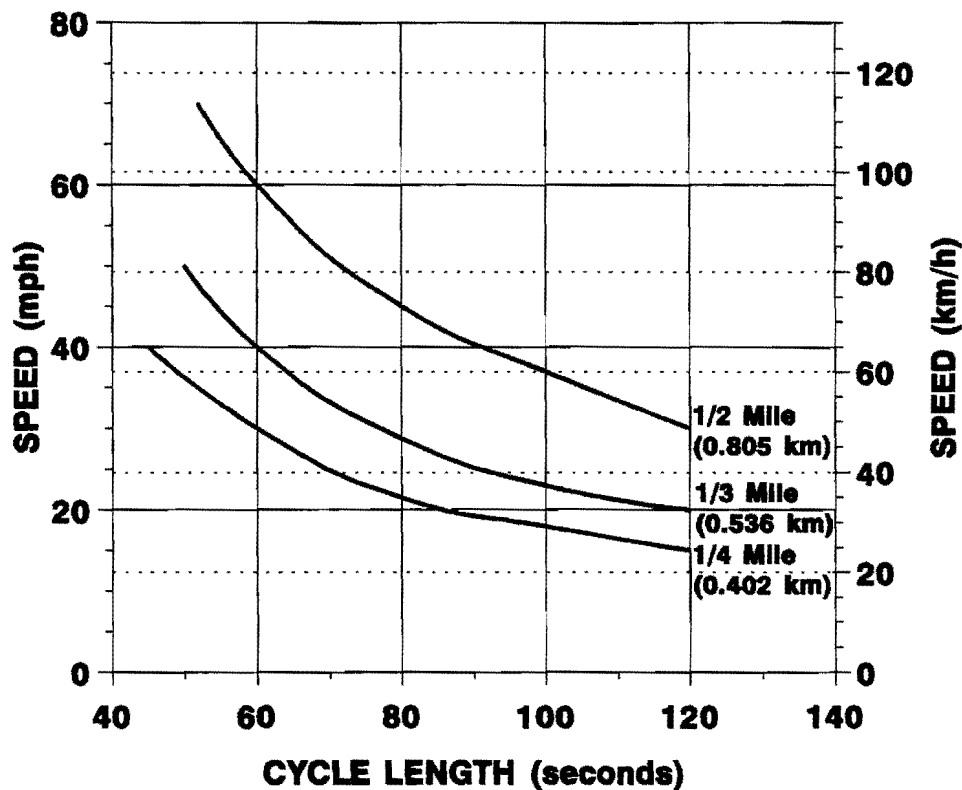
Figure C-1. Optimal Signal Spacing as a Function of Speed and Cycle Length (3).

The 0.804 km (1/2 mile) spacing also can be used during the off peak hours by utilizing shorter cycle lengths. Cycle lengths of 65 and 80 seconds result in off-peak progression speeds of 90 km/h (55 mph) and 70 km/h (45 mph) respectively when signals are located at 0.804 km (1/2 mile) increments. Cycle lengths less than 65 seconds result in speeds which are too fast for urban arterials and cycle lengths longer than 80 seconds result in speeds which are too slow.(4)

Stover, Demosthenes and Weesner used PASSER II-87 to generate progression efficiencies for various speeds at 60, 90 and 120 second cycle lengths. (3) Progression efficiencies were found to decrease rapidly as the spacing departed from the optimum signalized intersection interval. Table C-2 shows the decrease in efficiencies with slight variations from the optimal signal spacing 60m and 120m (200 feet and 400 feet) for cycle lengths of 60 and 120 seconds respectively.

Table C-2. Progression Efficiency (3).

Cycle Length Seconds	Signal Spacing Meters (Feet)	Approximate Progression Efficiency
60	470 (1540) 410 (1340)	0.31 0.05
120	930 (3040) 800 (2640)	0.34 0.08

Table C-2 also shows that as the cycle length increases, the progression efficiency increases. The maximum efficiency obtained using a 60 second cycle was just over 0.30, while for a 120 second cycle, the maximum efficiency rose to approximately 0.36. This increase in efficiency can be attributed to the reduction in lost time due to fewer phase changes per hour.

The Colorado Access Control Demonstration Project compared a 4-lane divided access controlled arterial having 0.804 km (1/2 mile) signal spacing and right turns only at the 0.402 km (1/4 mile) locations with an uncontrolled access roadway having 0.402 km (1/4 mile) signal spacing and full movement access every 0.201 km (1/8 mile). As shown in Table C-3, the controlled access condition shows substantially better traffic flow than the uncontrolled situation. The Florida Department of Transportation has concluded that an access controlled 4-lane arterial has the same capacity as a 6-lane roadway without access control.(21)

Table C-3. Effectiveness of Access Management on Traffic Congestion Parameters (5)

	Travel Speed km/h (mph)	Total Travel veh-hours/hour	Total Delay veh-hours/hour
Controlled Access	35 (22)	542	275
Uncontrolled Access	21 (13)	942	675
Percent Change	+69%	-42%	-59%

A NCHRP study completed in 1970 revealed similar results. (14)   This study evaluated the effect of signal spacing on the operating costs of the through traffic using the arterial. Varying cycle lengths, speeds, signal operation, and volumes were compared. "At high volumes, spacings should be at least 500m (1600+ ft); and there would be economic advantages from providing spacings up to 730 m (2400 ft). Additional cost to cross-street traffic would be extremely nominal." (14) Implementing 0.804 km (1/2 mile) signal spacings with the proper cycle lengths to suit the respective time periods, is the single most effective design tool used to manage congestion on major arterials.

Safety and Congestion Issues

The safety benefits of long uniform signal spacings has yet to be researched in-depth. Many of the newer reconstructed arterials with 0.804 km (1/2 mile) signal spacing are also fitted with other access control measures. This makes it difficult to determine what percentage of the benefits (accident reduction) can be attributed to each measure.

Research by Squires and Parsonson (6) found a strong correlation between the number of signals per mile (kilometer) and the number of accidents per million vehicle-miles (vehicle-kilometers) on four and six lane arterial roadways with either raised medians or C2WLTLs. The study showed that for each design alternative (raised median or C2WLTL and 4 or 6 lane cross section), the number of accidents increased linearly with the number of signals per unit of length.(6)

MEDIAL ACCESS

Introduction

Medians are the roadway element that separates traffic travelling in opposite directions. Since the median is defined as part of the "travelled way," restrictions in medial access are easier to mandate with the exercise of police power than restrictions on marginal access.(4) The design of medians as an access control measure involves the following elements: median type, median width, the geometrics of median openings, and spacings of median openings.

Median Types

Median designs fall into the following three classifications: non-traversable, traversable, and continuous 2-way left turn lane. The non-traversable design actively discourages medial crossings through the use of either a raised or depressed design. The traversable design is a flush or slightly raised median which vehicles may easily cross. The continuous 2-way left turn lane is a flush traversable center lane which provides storage for, and allows for deceleration of, left turning vehicles.(4)

Non-traversable

Although non-traversable medians have numerous design options, the most common urban median is 3.7 to 6.1 meters (12 to 20 feet) wide, with curbs.(7) To provide for dual left turn bays, the width of urban medians needs to be 8.5 to 9.1 meters (28 to 30 feet). A 8.5 meters (28 foot) median provides two 3.7 meters (12 foot) lanes and a 1.2 meters (4 foot) median. A median width of 8.5 to 9.1 meters (28 to 30 feet) also aids in restricting medial movements by providing adequate width to accommodate medial channelization.(23)

Non-traversable medians are the only positive access control measure to control or restrict left-turns. With the implementation of non-traversable medians, cross traffic and left turning movements on and off the major arterial can be eliminated or restricted to certain locations, and full movement access points are limited to major intersections. This results in three consequences: 1) increasing the throughput capacity of an arterial, 2) discouraging new strip development, and 3) greatly improving traffic safety.(6)

When adding non-traversable medians to an existing arterial, additional delay time occurs for left turning vehicles at the intersections due to the rerouting of mid-block traffic. However, through speeds increase approximately 10 km/h (5 mph) with the implementation of a raised or depressed median. (9)

Major arterials with high speeds generally have flush or slightly depressed medians for safety reasons. Raised medians create unsafe conditions when speeds exceed 45 mph (70 km/h). Rather than guiding the vehicle back onto the roadway, the raised median may cause the vehicle to overturn or go out of control.(6)

Traversable

As the name implies, traversable medians permit cross traffic and left turns along their entire length using a slightly raised or flush median design. Compared to raised medians, mountable or flush medians pose less of a safety hazard at higher speeds, but are less effective as an access control measure.(7) In areas with traversable medians, drivers often make maneuvers such as crossing or executing left turns despite pavement markings and signing which prohibit these movements. (4) Therefore, since access control is desirable along all segments of major arterials, traversable medians should not be used.

Continuous 2-Way Left Turn Lane (C2WLTL)

Continuous 2-way left turn lane treatments are flush traversable medians that allow maximum left turn access without impeding the arterial's through volume. In doing this, C2WLTLs reduce the delay of left turning vehicles at intersections.(6) Although C2WLTLs improve operational flexibility, they defeat the concept of principal arterials by permitting access along the entire left side of the roadway. C2WLTLs make no attempt to reduce points of conflict along the arterial.(9) This medial design becomes a real problem when the v/c ratio exceeds 0.8; there are too few gaps to allow unsignalized left turns and the turns are not focused at one point.

Safety and Congestion Issues

Many traffic accidents are a result of poor traffic flow and congestion. Therefore, studies which show a reduction in accidents may also indicate that the treatment also had a positive effect in reducing congestion.

Table C-4 summarizes the accident data analyzed in a research project by Georgia Tech.(8) The study identified 32 raised median sections and 50 C2WLTL sections. The researchers concluded that raised medians resulted in safer operation than C2WLTL's when the ADT exceeded 24,000 to 28,000 vehicles per day (vpd). As the ADT surpasses 24,000 vpd, gaps in the opposing traffic stream become shorter and more infrequent. This makes it increasingly difficult for vehicles to execute left-turns at midblock along a C2WLTL. A raised median forces all turns to the next intersection where left-turn phasing can eliminate the conflicts from the opposing traffic.

Table C-4. Summary of Accident Data (6).

	Total Accidents			Midblock Accidents		
	C2WLTL	Raised Medians	Percent Change	C2WLTL	Raised Medians	Percent Change
Accidents/MVM						
4 Lane Sections	8.99	7.67	-14.7	3.50	1.34	-61.7
6 Lane Sections	10.82	8.15	-24.7	4.19	1.92	-54.2
Accidents/Mi/Yr						
4 Lane Sections	99.45	70.91	-28.7	38.78	12.39	-68.1
6 Lane Sections	130.26	94.07	-27.8	50.46	22.13	-56.1

1 mile = 1.609 km

A before and after study of replacing a C2WLTL with a raised median on Memorial Drive, a high-volume, six-lane arterial in Atlanta, Georgia showed a 37 percent reduction in the total accidents and reduction of 48 percent in the injury accidents.(25)

With the construction of raised medians along an arterial, left-turn maneuvers are shifted to the median openings. In order to limit the speed differential found between left-turning vehicles and through traffic, and hence reduce congestion, a turn bay should be provided at all median openings. (7) Figure C-2 shows the length of turn bay required to limit the speed differential to less than 16 km/h (10 mph). Left-turn bays attempt to eliminate the "shock wave" effect of decelerating vehicles. The shock wave effect occurs where no turn bay is provided -- left-turning vehicles are forced to decelerate in the through lanes, and this causes through traffic to decelerate also. The queue of left-turning vehicles in a turn-bay of insufficient length may extend beyond the turn bay and block the through lanes. Turn bays with insufficient length not only produce shock waves in the through lanes, but they also pose problems for leading left-turn signal phasing. Short turn bays often prevent left turning vehicles from entering the turn bay in time to utilize the leading green. This situation results in excessive delays as the left turning vehicles are compelled to wait through the entire cycle. Congestion at intersections will be lessened by ensuring that left-turn bays are designed with sufficient length. Existing intersections with insufficient turn bays can be lengthened to improve the quality of flow through the intersection.
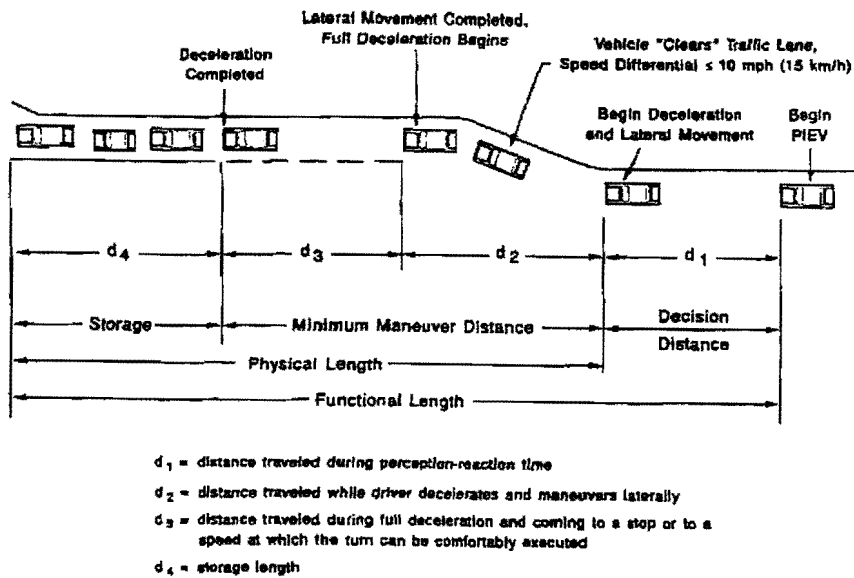
d₁ = distance traveled during perception-reaction time

d₂ = distance traveled while driver decelerates and maneuvers laterally

d₃ = distance traveled during full deceleration and coming to a stop or to a speed at which the turn can be comfortably executed

d₄ = storage length

Figure C-2. Determinants of the Intersection Maneuver Distance (20).

At intersections with high volumes of left-turns, the installation of dual left-turn bays (or in limited situations, triple left-turn bays) can accommodate high storage requirements without unreasonable turn bay lengths. Dual turn bays are also able to service greater volumes in less time than single bays -- dual bays can service nearly double the number of vehicles as single bays. The servicing of left-turns in a shorter time period allows a greater percentage of the cycle length to be allotted to the through movements. This has the effect of enlarging the green band, improving progression, and thereby reducing congestion along the arterial corridor. As Table C-5 shows, the desired median width to provide dual left-turn bays is 9 meters (30 feet).

If signalized, single left-turn bays are either permissive only, protective-permissive, or protected only. Historically, dual left-turn bays have been used with protective only phasing. However, there are conditions (low opposing volumes) in which protective-permissive phasing can be incorporated. The low opposing volumes apply to both through and left-turning volumes. The through volume must be low enough to provide ample gaps of adequate width; and for sight distance reasons, the opposing left-turn volume must also be low.

Median width

There are three primary reasons for requiring minimum median widths along non-traversable medians: 1) separate opposing traffic streams; 2) provide auxiliary lane(s) to decelerate vehicles and store left turning vehicles and U-turners; and 3) protect cross traffic at medial breaks.(7) Table C-5 shows the recommended minimum and desired median widths for arterials. Each of the given reasons aim to reduce congestion with an increase in the capacity of the arterial by limiting the through traffic's exposure to cross traffic and turning vehicles. Limiting the exposure improves congestion by allowing the through traffic to maintain a constant speed along the arterial.

Channelization of the median, to permit or restrict selected movements, is an important aspect of access management. As an access control measure, medial channelization is used for one or more of the following purposes: to separate conflicts; to protect and store turning and crossing vehicles; to block prohibited movements; and to segregate traffic movements having different speeds, directions, or right-of-way control.(20) As shown in Table C-5, 9 meters (30 feet) is desired to facilitate medial channelization. Nine meters (30 feet) is ample width to design for specific maneuvers such as left-turn ingress or egress only at a development.

Along arterials with non-traversable medians, intersection designs must accommodate U-turns at all median breaks -- both signalized and unsignalized. The provision of designated U-turn locations compensates for the loss of direct left-turn access due to the non-traversable median. Left-turn bays service U-turns if designed with an adequate width. On a 4-lane facility, Table C-5 shows that 13.7 meters (45 feet) is desired to permit U-turns.

Spacing of Median Openings

The spacing and design of medial and marginal access along arterials should be designed to eliminate or substantially reduce the speed differential between traffic leaving the roadway and through traffic. Table C-6 shows the relative likelihood of being involved in an accident is minimal when a vehicle is traveling at a speed less than that of other traffic. The table also shows that accident potential dramatically increases as the speed differential increases. (20) Other studies show that typical access designs without turn bays result in very high speed differentials. (20)

**Table C-5. Recommended Minimum and Desired
Non-Traversable Median Widths For Urban Arterials (4).**

Median Function	Minimum Width m(ft)	Desired Width m(ft)
Separation of Opposing Traffic Streams	1.2(4)	3(10)

Storage of Left Turning Vehicles
    Single Left Turn Bay
    Dual Left Turn Bay
	3.2(14)
	7.6(25)
		5.5(18)
		9(30)

Protection for Vehicles Crossing or Turning Left	7.6(25)	9(30)
Design for Selected Ingress or Egress Movements Only	5.5(18)	9(30)
Provide for U-Turns:inside (left) lane to outside (right) lane, passenger cars, 4-lane facility	13.7(45)	13.7(45)
Provide for U-Turns:inside lane (left) to outside (right) lane, passenger cars, 6-lane facility	10.1(33)	10.1(33)

Table C-6. Relative Accident-Involvement Rates for Arterial Roadways (20).

	Speed Differential km/h (mph)				
	0 (0)	-16 (-10)	-32 (-20)	-48 (-30)	-56 (-35)
Accident Rate Ratio, 0-Km/h (0 mph) differential 16-km/h (10 mph) differential	110 1	220 2 1	720 6.5 3.3	5000 45 23	20,000 180 90

While not addressing congestion directly, research shows that a non-traversable median improves capacity and safety. For example: The "... data indicated that the raised median results in less system-wide delay, increased roadway capacity, is safer for pedestrians, has a positive impact upon development and creates a more aesthetically pleasing environment." (9) The C2WLTL does help to reduce delay for left-turning traffic by providing continuous access, but system-wide delay on the roadway is less with a raised median than a C2WLTL. And, "The installation of a raised median is the best available technique to preserve the through-traffic movement function of an arterial street . . ." (35)

Interparcel circulation is often used to accommodate consolidating left-turn movements of several business at selected median breaks.(8) This interparcel circulation can be provided by the use of: joint parking lots, alleys, connections between adjacent parcels, or any combination of these. This allows circulation of localized trips between adjacent and/or nearby developments without creating conflicts with traffic on the street and thus contributing to congestion.

Intersections which are spaced too closely produce conflicts in the traffic stream, which in turn contributes to roadway traffic congestion. The distance required to eliminate conflicting intersections is the functional length. Four components shown in Figure C-2 make up the length of the functional area of an intersection, these are: 1) the length required to store queued vehicles, 2) the length needed to decelerate turning vehicles, 3) the length of the entering taper, and 4) the distance traveled during PIEV time.(9) The same elements are involved for left-turns as for right-turns. Minimum median spacings are calculated to eliminate any overlap in functional areas of intersection.

Conclusions

In terms of improved safety and capacity, as well as reduced congestion, non-traversable medians should be constructed on all major arterials. Constructing arterials 8.5 to 9.1 meters (28 to 30 feet) wide in design provides flexibility. This median width can accommodate dual left-turn lanes at major intersections and left-turn/U-turn lanes at minor signalized intersections; it also facilitates channelization at unsignalized intersections where full movements are not desired.

MARGINAL ACCESS

Introduction

Marginal access includes both public and private intersections with the major arterial. Although commercial driveways often carry traffic volumes comparable to public intersections, they have not been previously designed as such. All intersections, public as well as private, must be designed to enhance traffic flow along the arterial. As with medial access guidelines, marginal access guidelines are established to eliminate or reduce speed differentials greater than 15 km/h (10 mph) found between through traffic and right turn ingress movements.

Capacity and Delay

Uncontrolled marginal access results in reduced roadway capacity. Marginal access describes the access provided to unsignalized intersections caused by either private driveways or public roadways. One source estimates that, " . . . under average conditions, the capacity of a four-lane arterial street with a 70 km/h (45 mph) speed limit will be reduced by one percent for every two percent of the traffic that turns between the right lane and the driveways at unsignalized intersections." (12) Consider the following example.

> A four lane major arterial has an initial capacity of 1600 vph in one direction without marginal access. Currently the roadway is carrying 1500 vph, which is under capacity. If driveway access were permitted, what would be the effect on the arterial?
>
> Capacity will be reduced by 1% for every two percent of the turns. Assuming 20% turns per mile (10% into driveways and 10% out of driveways), roadway capacity will be reduced by 10%. The capacity with driveway access can be estimated as:
>
> $$Reduction = 0.10 * 1500 \ vph = 150 \ vph$$
>
> $$Capacity \ w/Driveways = 1600 \ vph - 150 \ vph = 1450 \ vph$$

The capacity for the major arterial has been reduced to 1450 vph. Demand now exceeds capacity and congestion will occur along the arterial. Therefore, by allowing marginal access along the major arterial, capacity has been sufficiently reduced to create undesirable levels of congestion.

Another study indicated that multiple driveways at close spacings do not decrease vehicular delay for vehicles turning onto an arterial. (14) In addition, contrary to popular opinion, closely spaced driveways do not increase the ability of the arterial's through lanes to absorb traffic. (13) Major and Buckley reported as early as 1962 that the ability of an

arterial to absorb egress traffic increases as the driveway spacing increases. (27) For high-volume traffic generators, in order to reduce delay to vehicles entering the traffic stream, driveways should be spaced at distances greater than 1.5 times the distance to accelerate from zero to the speed of traffic. (27) The resulting minimum driveway spacing for various acceleration rates are shown in Table C-7.

**Table C-7. Minimum Spacing Between Driveway Access Points
to Maximize Egress Capacity (42).**

Speed km/h (mph)	Spacing meters (feet)
50 (30)	105 (340)
55 (35)	140 (450)
65 (40)	190 (625)
70 (45)	260 (850)
80 (50)	350 (1150)
90 (55)	455 (1500)

"Under high volume conditions, even a few turning movements will cause serious problems in the through traffic stream. It is evident from observation that the problem is the number and spacing of the access points more than the number of vehicles. Frequent unsignalized access points of short spacings result in lower egress capacity from the abutting properties and increased delay to the vehicles waiting to enter the arterial." (14) Therefore, by providing adequate spacing between unsignalized access points, capacity and traffic flow will be improved and congestion reduced on both the arterial and at the access points.

Right Turn Bays

When marginal access is allowed along major arterials, right turn bays (or in some limited cases, continuous right turn lanes) are recommended. As with left turn bays, right turn bays/lanes allow turning vehicles to decelerate without seriously impeding through traffic. There are two primary situations in which turning traffic impedes on the through traffic: along arterials where no turn bays or turn lanes are provided, the speed differential, due to the deceleration of turning vehicles, exceeds 15 km/h (10 mph); and at signalized intersections, a turn bay with inadequate length does not allow turning vehicles to exit the through traffic stream such that the traffic behind the turning vehicle is able to close the gap formed by the turning vehicle. Closing the gap and obtaining a low headway is crucial to maximizing an intersection's capacity.

At intersections operating under congested conditions due to high volumes of right-turning vehicles, extending the length of an existing turn bay or constructing a dual right-turn bay can improve the flow of both mainline and turning traffic. Both measures increase the storage capacity for right-turning vehicles, and the dual right-turn bay has the additional benefit of being able to service nearly twice the number of vehicles as a single turn bay.

In determining the spacing required between marginal access points, the functional upstream area of the intersection must be calculated. The process is the same for public street intersections and private access drives except that the site design of private access drives should be designed so that queue storage for traffic entering the site is accommodated on the site, not on the public street. However, provide storage when designing for the intersection of two public roadways.

Safety and Congestion Issues

Driveways and unsignalized intersections introduce conflicting movements into the traffic stream which affect roadway safety and congestion. A study of Chicago suburbs indicated that over 11% of all accidents on major arterials involved turns in and out of a driveway.(12) Other studies have shown similar percentages, such as 14.4% of two-vehicle accidents on county roads in Indiana involved driveways and 6.5% of accidents in Los Angeles county involved uncontrolled driveway access.(15) Another study reported that each accessible driveway along an arterial street adds between 0.1 and 0.5 accidents per year, and driveway accident rates decrease as the number of accessible driveways is decreased.(16)

In a recent article based on a FHWA report on access management, safety research indicated that there was a direct correlation between the accident rate and the number of uncontrolled access points, as shown in Figure C-3.(17) As the number of businesses and driveways increase per mile, side friction and accident rates also increase accordingly. The increase in side friction not only leads to more potential accidents, but it also indicates congested traffic conditions. Therefore, to reduce the accident rate and limit congestion on major arterial roadways, driveway access must be limited and controlled. Another study (21) reinforced the correlation between accident rates and driveway spacing; these data are shown in Table C-8.

Table C-8. Effects of Driveway Spacing on Accidents (21).

	Accidents per Million Kilometers Traveled
0-12 Access Points per Kilometer	1.2
Over 12 Access Points per Kilometer	2.5
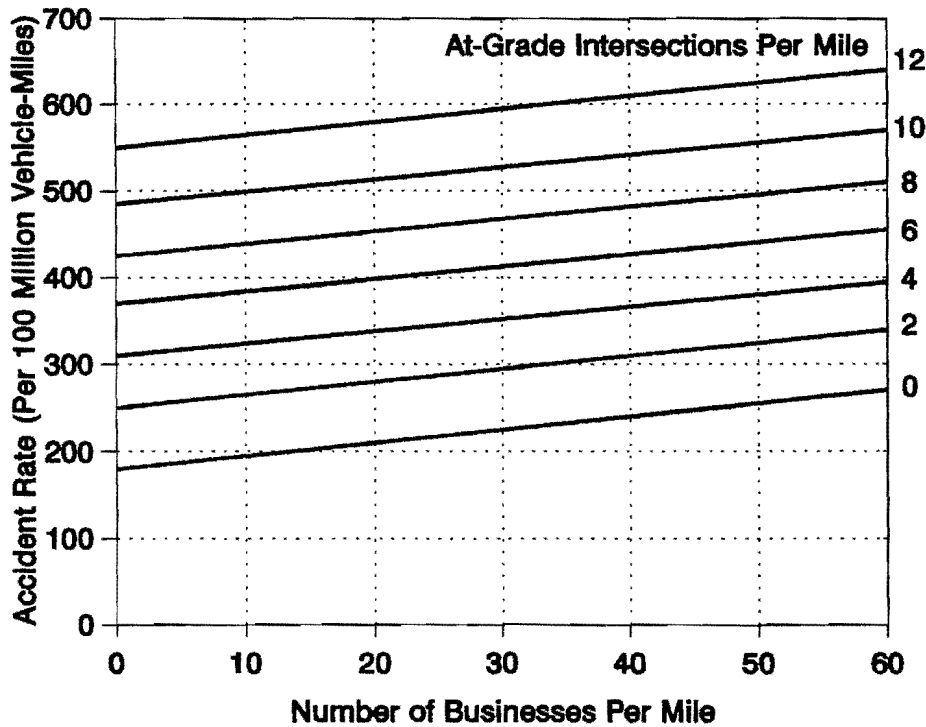
**Figure C-3. Accident Rate on 4-Lane Divided Arterials
Due to Uncontrolled Access [7].**
1 mile = 1.609 kilometers

In addition to right-turn bays or lanes, consolidated driveways, proper design of driveway width and throat length, and driveway visual cues each contribute to the lessening of congestion along arterials. Visual cues denoting driveway entrances reduce abrupt decelerations and ease the transition from the arterial to the driveway. Limiting the deceleration along the arterial keeps traffic flowing smoothly. The consolidation of driveways limits the potential conflicts encountered along the arterial. Consolidation can occur either by closing driveways within one development or by closing driveways of adjacent developments and providing a shared driveway with cross-parcel circulation.

The width of the driveway (or cross street) and the intersection's corresponding curb return radius directly impact the speed at which vehicles can turn off of the arterial. Obviously, as the driveway width and curb return radius increase, the speeds of the turning vehicles also increase.

CONCLUSIONS

Efficient marginal access management produces benefits similar to those obtained from medial access control. Controlled driveway access along high volume arterial streets results in lower accident rates, higher roadway capacity and decreased vehicular delay for turning vehicles. Higher traffic volumes are able to operate safely by limiting the speed differential between through volumes and turning vehicles and thereby reducing congestion. The primary marginal access control measures are:

- Based on the speed of the arterial, mandate minimum spacings to be allowed between intersections.
- Provide right-turn bays/lanes at all intersections.

One of the greatest problems encountered along undeveloped roadways is the belief that low volume arterials will tolerate more direct land access because they provide less through movement. However, as traffic volumes increase, the direct access will prove to be a hinderance. It is easier to start without access than to try to retrofit an arterial and take accesses away from businesses and residents at a later date.(9)

Implementing a long range access management plan requires cooperation between local governments, state agencies and developers. Although some developers often want unlimited access, many experienced developers also realize the long term benefits of efficient access control including stable activity patterns and property values.

Access control measures are effective tools for mitigating roadway traffic congestion problems. The most effective, especially when used in combination, are: long uniform signal spacing; non-traversable medians which restrict left-turns at unsignalized access locations; improved design of marginal access; and the provision of turn bays at all medial and marginal access locations -- both public and private.

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APPENDIX D

THE CALIFORNIA LEGISLATION

All references cited with the large underlined number in this Appendix are identified in the References section following Chapter 3.

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The main requirements and activities of the California Legislation, as summarized by the Alameda County CMP (5), are as follows:

1. Sets up a performance review process, by mandating the designation of a network of transportation facilities which will be periodically monitored for congestion, and by requiring the designation of service standards for roadways and transit;

2. Promotes use of alternatives to the single occupant private automobile through requirements for Trip Reduction Ordinances and Transportation Demand Management measures;

3. Promotes integration of decisions about land development, transportation investment and air quality by requiring a process to determine the impacts of local development decisions on the regional transportation network;

4. Requires a 7-year investment strategy, referred to as a Capital Improvement Program (CIP), to be updated annually, to support the Congestion Management Program goals, and links project eligibility for regional/state funding to the CIP;

5. Requires a computerized travel model and uniform data base for estimating future transportation needs and impacts; and

6. Requires the designation of a Congestion Management Agency (CMA) in each urban county, to develop and update the Congestion Management Program and monitor its progress over time.

The California Legislation also requires that, at a minimum, all state freeways and principal arterials be included in the designated network. Any highway or roadway which is designated as part of the system may not be removed. In addition, any newly constructed highway or roadway must be designated as part of the system (1).

Furthermore, the legislation requires agencies to use Level of Service (LOS) to evaluate all roadway segments defined in the network. LOS must be measured by Circular 212, the latest edition of the *1985 Highway Capacity Manual* (2), or a method consistent with the *Highway Capacity Manual*. However, the California Legislation does not specify which LOS value indicates congested conditions. The legislation states that the LOS standard shall not be lower than LOS E or the current level, whichever is farthest from LOS A. Therefore, agencies are permitted to specify LOS values as low as possible so that improvements on those segments will not be required (1).

The California Legislation also requires that standards be established for the frequency and routing of public transit. Transit standards also work in partnership with the LOS standards utilized for the road network (62). In addition, the legislation requires that the trip reduction and travel demand management element promote other modes of transportation, such as bicycles, carpools, vanpools, transit, flexible work hours, and parking management programs. Furthermore, land use analysis programs and the development of a capital improvement program are required.

Based on the requirements of the California Legislation, several major elements have been included in most of the county CMPs. The nine main elements of the Santa Clara County CMP (3), which are representative of most California CMPs, are as follows.

1. *System Definition Element* - Define all roadways which will be part of the designated congestion management network.
2. *Traffic Level-of-Service Standard Element* - Adopt LOS standards for the CMS network and describe the methodologies used for evaluating LOS.
3. *Transit Service Element* - Describe the transit system services, standards, and facilities for the county.
4. *Trip Reduction and Transportation Demand Management Element* - Describe strategies to improve the LOS on the system by reducing vehicle trips.
5. *County-wide Transportation Model and Database Element* - Describe the transportation model to be used in the county and how it and its database will be used to evaluate transportation impacts on the designated network.
6. *Land-use Impact Analysis Program Element* - Describe procedures which will be used for analyzing the transportation impacts of land-use decisions.
7. *Capital Improvement Program Element* - Consists of a prioritized list of transportation facility improvements for inclusion in the Regional Transportation Improvement Program and the State Transportation Improvement Program.
8. *Annual Monitoring and Conformance Element* - Describes the monitoring and conformance practices which will be used to comply with the annual monitoring requirement of the state legislation.
9. *Deficiency Plan Element* - Describes the process for preparation and approval of deficiency plans for facilities which do not meet the LOS standards.

APPENDIX E

STATE-OF-THE-PRACTICE:
MEASURING CONGESTION

All references cited in this Appendix with large underlined numbers are identified in the References section beginning on page 29 following Chapter 3.

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In order for congestion management systems to be effective, the management agency must know the current level of congestion on all freeways and principal arterials in their network. Current congestion measures vary from agency to agency around the country and include travel time, spot speeds, average running speed, midblock volumes, intersection turning movements, and delay. A major consideration in selecting a congestion measure is the cost associated with the measuring activity, such as with data collection and analysis.

Throughout the years, many different methods have been used in various parts of the country to evaluate congestion. Existing methods for measuring congestion are described in detail in Appendix B. Each method is discussed, along with its applicability in measuring spot, corridor, or areawide congestion levels, and its effectiveness for use in a congestion management system.

State-of-the-Practice for Freeways

The Alameda County CMA, Bay Area MTC, CALTRANS Districts 4 and 11, Contra Costa County TA, and the Santa Clara County CMA all use travel time to measure freeway congestion using the floating car technique. CALTRANS-4 collects extensive travel time data and supplies the information to the other agencies. The Alameda County CMA does not use the CALTRANS data since the CMA believes that the data are too old by the time it is received and not of any value to them. Therefore, the Alameda County CMA has contracted with a private consultant to collect travel time data for them.

In Alameda County, the measurement of LOS is based on average travel speed, measured using the procedure described in the *Manual of Traffic Engineering Studies* (4). The private consultant hired to perform the study uses the "floating car" technique to record travel times between checkpoints on the system. Average travel speeds on a segment were then derived from the measured travel time and the measured distance for each roadway segment. The computed average travel speeds were then compared to Tables 11-1 and 3-1 from the *1985 HCM* to determine the LOS for that segment (5). Travel time runs were made for both freeways and arterial streets on all 370 kilometers (230 miles) of roadway in their defined network.

The data were collected during two different study periods; one in August 1991 and the other in October 1991. Travel time runs were completed during the afternoon peak hours of 4 to 6 pm on a Tuesday, Wednesday, or Thursday only, as required by the Alameda County CMP. In most cases, six travel time runs were completed on each roadway segment. If no congestion had been reported and travel speeds were consistently very high, travel time runs were terminated after four or five runs. In some cases, more than six runs were required in highly congested areas where travel speeds fluctuated (5). The lower resulting LOS for a segment from the August or October study period was established as the existing LOS value for that segment.

After the initial measuring period, the consultant determined that separate travel time runs needed to be made for ramps at freeway to freeway interchanges since conditions at

these connections sometimes have different characteristics than a general freeway segment. LOS F for the ramps at the interchange would occur when speeds dropped below 50 percent of free flow speeds. In August 1992, travel time runs were completed on a number of ramps at freeway to freeway interchanges. Two locations were evaluated to have LOS F conditions, and have since been added to the baseline congestion levels established for the Alameda County CMP network (6).

The floating car technique used by CALTRANS-4 involves vehicles which travel in the normal travel lanes and record the length of time necessary to travel the segment, similar to the technique used by the Alameda County CMA. The driver tries to "float" within the traffic stream by passing as many vehicles as pass him. The cars are equipped with a computerized system which records car speed and time as each car travels along a particular freeway segment (7).

During "full" data collection, at least three cars travel on each segment during the peak period on weekdays only. A segment is 11 kilometers (7 miles) or less in length. The effects of minor accidents or other recurring delay is included in the travel time runs. Delays due to major accidents are excluded. A single car is used to check if travel times may have changed since the last "full" data collection period. If there is evidence that the travel time may have changed, a "full" data collection effort is begun.

The Santa Clara County CMA uses the travel speed data collected by CALTRANS-4 for measuring congestion on urban freeway segments. The speed data are converted to LOS using the 1985 HCM freeway travel speed criteria. For rural freeways, volume-to-capacity ratios are determined from available data and then converted to LOS values using the 1985 HCM procedure for two-lane highways (3).

As part of their growth management program, the Contra Costa Transportation Authority (CCTA) requires the development and implementation of action plans for designated Regional Routes which comprise their defined network. One component of the action plan is to establish baseline congestion levels by collecting and analyzing collected data. The data to be collected may include intersection and freeway LOS, travel times and intersection delays, average auto occupancy, existing transit service and use, existing land use, approved development, General Plan land use designations and buildout potential, and capital improvements planned by local agencies (8).

As part of a recent corridor analysis in Contra Costa County, congestion levels were determined at many locations along the corridor (9). For the freeway portion of the corridor, weekday travel time runs were conducted during the morning and evening peak-hours using the "floating car" technique. Three runs were made in each direction during both peak-hours.

The Bay Area MTC anticipates establishing a standard and uniform evaluation of the Bay Area congestion -- one performance measure to accurately measure congestion. The chosen performance measure would be consistent over time, apply to different locations

within the same jurisdiction, and also apply to a multimodal system. When, or if, this performance measure is discovered, the MTC will try to mandate its implementation in the entire Bay Area. This proposed evaluation process of one all encompassing performance measure is resisted by different local jurisdictions. The Bay Area MTC is looking for performance measures to implement on an areawide, system level scale. In investigating the areawide measures, the MTC looks at the data currently available, how much of these data are needed, the costs associated with the data collection process, and whether the data are useful.

Other agencies measure congestion in a variety of ways. The Los Angeles County Metropolitan Transportation Authority relies on CALTRANS to measure the LOS on freeways as a function of travel speed and duration of congestion. This procedure is consistent with the *1985 Highway Capacity Manual Methodology*. LOS values identified in the 1992 CMP evaluate LOS based on volume to capacity ratio and operating speed (10).

The Riverside County Transportation Commission measures congestion with v/c ratio using data provided by CALTRANS-11. Speed data are not used in any form by Riverside County to measure congestion. Riverside County determines LOS using a "delay" analysis for CMP purposes. Agency staff evaluated different LOS methodologies and determined that the HCM procedures incorporating delay were the most appropriate methodologies for determining LOS (11).

The San Diego Association of Governments measures freeway congestion using the *1985 Highway Capacity Manual* procedures for determining LOS values (12). The SANDAG determines LOS based on weekday traffic volumes adjusted for peak-hour and directional factors. Freeway capacity is generally assumed to be 2,000 vehicles per hour per lane and is adjusted to account for terrain on a link by link basis. CALTRANS-11 also checks the calculated LOS values where needed by measuring travel times with the floating car technique.

The San Joaquin County Council of Governments measures congestion using LOS based on the State of Florida's *LOS Standards and Guidelines Manual for Planning*. CALTRANS District 10 made an official finding which determined that the use of the Florida method is consistent with the *1985 Highway Capacity Manual* and with the State of California CMP law (13). The Florida method sets upon generalized LOS maximum volume tables for different roadway types. Based on the *HCM*, the tables use default assumptions for traffic, roadway and signal characteristics. The measurement evaluation is a four step process: determine the basic characteristics of the road; divide the road into segments; determine segment characteristics; and match median average weekday traffic volumes with the appropriate facility-type table. For freeways, the LOS calculations are based on published annual traffic volumes obtained from the state DOT or more recent counts obtained from the DOT district office.

The Chicago Area Transportation Study (CATS) measures freeway congestion using the Illinois Department of Transportation's traffic surveillance system. CATS proposes to use minute-miles of delay to measure freeway congestion, such as the Illinois Department of Transportation is currently using. This is made possible by having detectors at half-mile intervals along the freeways. Minute-miles of delay is computed for each five minute period for detectors operating in congested conditions by multiplying five minutes times the number of miles represented by the congested detectors (14). Congested conditions occur when loop occupancy passes 30%. Each detector represents conditions for each quarter-mile section on either side of the detector.

Minute-miles of congestion is a summary measurement which takes into account all the variables which contribute to the complete range of traffic operations. The measurement includes the effects of accidents, wet pavement, disabled vehicles, and other causes of congestion. CATS analysis has shown that congestion quantified by this summary method correlates with total travel time. Minute-miles of delay is obtained each peak period if a sophisticated traffic monitoring/detection system is in place, such as implemented in the Chicago Area and planned for the San Francisco Bay Area freeways.

However, the minute-miles of delay method is dependent on a completely accurate network of detectors requiring a very high degree of reliability. Studies have shown that loop detectors only provide accurate information when maintained on a regular basis (15,16). Pavement movements, high volumes of traffic, and construction work all effect loop operations. Operating characteristics of loop detectors are different with odd-sized vehicles, especially high profile trucks and motorcycles.

It should also be noted that the minute-miles of delay method is only applicable to freeways. This method is not applicable to other modes of transportation, such as transit and ferry operations. While minute miles of delay may be acceptable for use in monitoring freeway conditions, another method must be utilized to measure congestion levels on other modes of transportation. It is in the best interest of congestion management systems to utilize only one method of congestion measurement to monitor mobility conditions for all modes of transportation.

The New York DOT measures congestion using vehicle hours of delay (VHD). A delay model was adopted in December 1989 as the best available tool for measuring VHD. The delay model assumes that travel at LOS D is acceptable. Therefore, excess VHD is the delay resulting from LOS E and F conditions. Excess VHD over a 24 hour period is currently being used by the New York DOT to measure congestion.

For each hour of the day, the delay model determines whether travel is at LOS E or F. If it is, travel time is then computed based on average operating speed. VHD is then calculated as the difference between travel time at LOS E or F and travel time at LOS D as described below:
Capacity values for LOS D conditions are determined from several tables for different roadway cross-sections/geometries. If the existing or projected volume exceeds the LOS D

$$Travel\ Time\ =\ \frac{Section\ Length}{Average\ Operating\ Speed}$$

$$\frac{VHD}{Hour}\ =\ \frac{Vehicles}{Hour}\ (Travel\ Time\ at\ LOS\ E\ or\ F\ -\ Travel\ Time\ at\ LOS\ D)$$

$$Daily\ VHD\ =\ \sum\ \frac{VHD}{Hour}$$

capacity, excess delay exists on that section of roadway. When volumes for consecutive hours increase from LOS D to E, the delay model assumes the volumes increase linearly and VHD is computed for the partial hour of congestion (17).

The Capital District Transportation Committee (New York) measures congestion using travel times over the network obtained by modeling using TMODEL2. A comparison between model runs and actual travel times has not been documented. Capital District TC staff members "collect" travel times by noting the time it takes to travel to and from work. Comparisons between the modeled travel times and the "collected" travel times are perceived to be very good. The Capital District TC also uses excess vehicle hours of delay. The Draft CMS indicates their objective to keeping excessive VHD to no more than 1.1 vehicle hours per 1,600 vehicle kilometers (1,000 vehicle miles) of travel (18). For all congestion objectives indicated in the Draft CMS, excess VHD was noted as the proposed performance measure.

The Washington Department of Transportation reported that spot speed, average running speed, and travel time are all used somewhere within the state to measure congestion. Local TMAs must decide how to measure congestion in order to accomplish the goals and objectives they have established. The Washington DOT accepts any or all of these measures. Travel time data are collected periodically by the DOT as needed to document the changes in urban mobility. The license plate matching technique has been found to be the least costly way to collect large amounts of travel time data.

The Southwest Washington Regional Transportation Council has selected a peak-hour, peak-direction corridor volume-to-capacity (V/C) ratio as its measure of congestion for the Vancouver CMS. This value for the corridor is actually an aggregation of the individual V/C ratios for each segment in the corridor. This process includes calculating the V/C ratio and weighing the V/C ratio for each link by the vehicle-kilometers of travel (VKT) (vehicle-miles of travel (VMT)) for the link (19). The "capacity" to be used will be "acceptable volumes" based upon functional class, number of lanes and typical conditions, etc. It is expected that these "capacities" will be similar to those presently used in the coded highway network. Development of the "acceptable volumes" will be done in Phase II of the current CMS study. It is expected that they will be a refinement of, and similar to, the volumes presently used in the modeling process. With the exception of the Vancouver CBD,

there are no plans to calculate average V/C values for subareas, or areawide, for use in the CMS.

The SW Washington RTC chose this particular measure for several reasons. The method is simple, the data requirements are relatively inexpensive, the method is presently being used, the methodology (including the "acceptable volumes") is understood by technical and non-technical people and by decision makers in the Vancouver/Clark County area, and the RTC recognizes a need to have uniformity (i.e. a connection) between existing (counted) and modeled (both current and forecast) performance measures.

The North Carolina DOT measures congestion on freeways using the Florida DOT procedure based on capacity and volume counts. Travel time and speed data are rarely collected. Currently, congestion levels are only measured as part of air quality related projects or as part of a research project.

The Charlotte DOT does not measure freeway congestion in the Charlotte area. All freeway measurement is left for the NC DOT. However, the Charlotte DOT makes travel time/speed runs on the freeways. Five runs are made in the AM and PM peak direction every two years. The travel time data on radial roadways are collected by the Charlotte DOT staff on the way to/from work. Data on circumferential routes are collected before and after work, and the employees receive overtime pay. The collected data are published in a report every year, so about half of the data are new and half of the data are from the previous year. Again, these data are not used for determining congestion levels, and the Charlotte DOT does not have any set standard for the decline of congestion based on travel time.

The following three agencies do not currently measure freeway congestion: Bi-State Regional Commission (Illinois); Puget Sound Regional Council (Seattle, WA); and St. Cloud Area Planning Organization (Minnesota). Both the Bi-State Regional Commission and the St. Cloud APO have only isolated problems with congestion, and therefore do not need to measure congestion levels. The Puget Sound Regional Council does not measure congestion as an agency, but each city within the council measures congestion independently. LOS is typically the measure used for freeways by each city.

The Puget Sound RC has expressed an interest in participating in the proposed test of methodologies for collecting urban travel time data for the FHWA Office of Highway Information Management. The Puget Sound RC expressed interest in the project because they " are committed to integrating travel time measurements into [their] existing travel time data collection programs, [their] Congestion Management Systems (CMS) planning and [their] ongoing program of transportation planning and modeling development." (20)

The Denver Regional COG, Pikes Peak COG, and Colorado DOT have begun a joint effort to identify common issues relative to CMS. At present, the three agencies have not agreed upon a common measure of congestion. They hope that the same method can be

utilized by all three agencies even though their definitions of congestion will likely be different.

All of the measurement techniques used by various agencies in determining freeway congestion are summarized in Table E-1, pp. 114 to 116. For ease of use, the measurement techniques are listed by agency in alphabetical order.

State-of-the-Practice for Arterial Streets

A variety of methods are used to measure arterial street congestion. The Alameda County CMA measures travel time with the floating car method, as described in the previous section. Travel time data are then converted to travel speeds and compared to the values in the *1985 Highway Capacity Manual* to determine LOS for that particular segment.

The Contra Costa TA measures congestion on arterial streets using a method similar to the *Circular 212 Planning Method* in accordance with the *CCTA Technical Procedures* (21). The method is identical to the *Circular 212 Planning Method* except that the intersection capacity has been increased from 1500 vph to 1800 vph. Saturation flow rates were measured at four intersections in the county in 1990, and the data confirmed that capacity levels based on a saturation flow rate of 1800 vph are appropriate for Contra Costa County. The method calculates the sum of critical volumes for an intersection and then compares those values to a modified version of Circular 212, Table 6, to determine appropriate LOS values for the intersection (21).

During a recent corridor analysis in Contra Costa County, congestion levels were determined at many locations along the corridor (14). At unsignalized intersections, the *1985 Highway Capacity Manual* unsignalized intersection methodology was used. At unsignalized intersections, delay is only experienced by left turns from the major street and by the stop controlled side streets. The LOS values determined at these locations are different for each movement and are based on the "reserve capacity" calculated for each movement.

The Santa Clara County CMA measures congestion on arterial streets using the 1985 HCM intersection analysis operations methodology. A private consultant evaluated five different intersection LOS methodologies (Circular 212 Planning Method, 1985 HCM, Golden Triangle Method, City of San Jose Method, and City of Palo Alto Method) before recommending the 1985 HCM method for use in the CMP. The major issues involved in selecting the LOS methodology included ease of use, data collection efforts, ability to use the method for evaluating future conditions, and accuracy (22).

The Los Angeles County Metropolitan Transportation Authority and Riverside County Transportation Commission both measure arterial street congestion using v/c ratios calculated by Intersection Capacity Utilization (ICU) method and then converted to LOS. The ICU method assumes a capacity of 1600 veh/lane for all through and turning lanes, with 2880 total for dual turn lanes. LOS values are assigned based on overall intersection v/c

ratios. Additional adjustments for exclusive + optimal turn lanes, right-turns on red, or other factors are left to the discretion of the local agencies.

The Bay Area Metropolitan Transportation Commission uses intersection LOS to measure congestion. LOS is determined by the individual CMAs within the Bay Area MTCs jurisdiction using either delay or v/c ratio. County CMAs have the responsibility for congestion measurement under California Law. This results in LOS values which may or may not be reciprocal among the nine counties within the Bay Area. The Contra Costa County Transportation Authority also uses LOS, but they determine LOS using delay procedures in the *1985 Highway Capacity Manual.*

The San Diego Association of Governments calculates LOS on urban and suburban arterials based on procedures in the *1985 HCM* (12). The HCM procedures were recommended to the SANDAG for use after a study was completed analyzing the different methods of calculating LOS. The study concentrated on urban and suburban arterials, and recommended using the 1985 HCM procedures. Chapter 11 is used for calculating regional arterial LOS, while Chapter 8 is used for calculating LOS for two-lane rural highways (23).

The Santa Clara County Congestion Management Agency mandates that each city report LOS values for 150 to 170 intersections. Fifteen-minute mechanical counts are made to identify the highest 60-minute period. Then, manual counts are made for usually six 15-minute intervals to obtain the turning movement counts for the peak hour. Delay is then calculated to determine intersection LOS. Each city is free to choose their own default values and other assumptions.

CALTRANS-4 measures surface street congestion using LOS. Volumes are determined by directional tube counts by one hour intervals. These counts can be used to determine the v/c ratio of a particular segment. LOS criteria for intersections based on lane volumes were provided by CALTRANS-4, but no explanation was provided as to how or when these criteria are applied towards measuring surface street congestion.

The San Joaquin County Council of Governments uses the Florida DOT Method to calculate congestion on arterial streets, as described in the previous section. The city or county must determine if the segment characteristics have changed, including number of lanes and urban/rural status. Median average weekday traffic volumes are then used for each arterial segment that is analyzed (13). Each local agency within the county is responsible for measuring arterial congestion within its jurisdiction.

Within the jurisdiction of the Chicago Area Transportation Study, measurement of surface street congestion is project/location specific. Locations to be studied are identified by the City of Chicago or by a member of the Regional Council of Mayors. The local agency collects the necessary turning movement counts and, if capable, performs all the analysis. CATS staff members review the results and may perform analysis, if needed, but there is no continuous surface street measurement program currently in place.

The St. Cloud Area Planning Organization (Minnesota) measures arterial street congestion using directional traffic counts. Fifteen minute mechanical counts are made at approximately 200 locations annually on the principal and minor arterial systems. An equal number of locations are counted by the Minnesota DOT and the St. Cloud APO (about 100 each). The St. Cloud APO has also begun identifying measures for use in their Transportation Systems Management (TSM) program. The objective of TSM is to improve system efficiency and productivity by coordinating the movement of automobiles, public transit, taxis, trucks, pedestrians and bicycles. To date, TSM data collection efforts have only involved automobile and public transit characteristics on the arterial and collector street systems. Measures must be identified in order to evaluate system efficiency for all of these modes (24).

The New York DOT measures congestion using vehicle hours of delay, as previously described for freeways. Capacity values for LOS D conditions are determined from several tables for different roadway cross-sections/geometries. If the existing or projected volume exceeds the LOS D capacity, excess delay exists on that section of roadway. The vehicle-hours of excess delay is then calculated based on the time in which the volume exceeds the designated LOS D capacity.

The Capital District Transportation Committee (Albany, New York) uses intersection delay calculated from traffic volumes, number of lanes, and generalized cycle length (i.e. short or long) and "generalized"/"acceptable" link capacity. Intersections are analyzed using TMODEL2, which uses several different combinations of the indicated variables. Regression analysis was used to relate intersection delay with approach volumes. Observed travel time data are not currently obtained, but will be collected in the summer of 1993. However, the Draft CMS indicates that the performance measure to be used for obtaining all objectives will be excessive vehicle hours of delay (23).

As part of the Capital District's TSM program, 119 intersections were counted and analyzed during the first year of the program. Nearly 60 percent of the intersections will require some type of improvement in order to meet adopted standards. Improvement is required if one or more lane groups or movements is performing at LOS D or worse determined by procedures in the 1985 HCM. About 55 percent of the intersections which require improvements would benefit from low cost improvements such as retiming signals, pavement re-striping, or shoulder stabilization (25). The TC plans to measure congestion levels on 100 additional intersections during the second year of the TSM program.

The Puget Sound Regional Council utilizes both v/c ratios and delay to measure arterial congestion. Each city selects its own method with turning movements counts being the most common form of data collected. Some counties use areawide intersection delay in which selected intersection delay is measured and the composite is applied to the system as a whole.

The Washington Department of Transportation reported that the following measures are all used somewhere within the state to measure congestion on arterial streets: spot

speed, average running speed, midblock volumes, turning movements, and intersection delay. Local TMAs must decide how to measure congestion in order to accomplish the goals and objectives they have established.

The Southwest Washington Regional Transportation Council has selected a peak-hour, peak-direction corridor volume-to-capacity (v/c) ratio as its measure of arterial street congestion for the Vancouver/Clark County CMS. The procedure is identical to the one used for freeways except for the magnitude of the "acceptable" volumes used. The "acceptable" volumes/capacities are based upon cross-section, access, traffic control, etc.

The North Carolina DOT measures arterial street congestion using v/c ratios. Neither observed or calculated delay are used for arterial streets. The v/c ratio obtained by a traffic model is determined for a particular arterial and then converted to a LOS value.

The Charlotte DOT measures congestion on arterials by determining the sum of critical volume to capacity ratio (v/c) at signalized intersections (31). All signalized intersections are counted for a 12-hour period between 7 am and 7 pm. The critical v/c ratio is determined using the 1985 HCM. The DOT indicated that delay is not used because the HCM gives misleading (long) delay values due to the fact that all of the traffic signals in Charlotte are fully activated and coordinated in one of 22 signal systems. Adequate green time is given to the arterial streets to accommodate the arterial street volume, and side streets are allowed to "back-up."

The San Diego Transportation Management Association, the Southern California Association of Governments, the Bi-State Regional Commission and CALTRANS-11 do not measure arterial street congestion.

All of the measurement techniques used by various agencies in determining arterial street congestion are summarized in Table E-1, pp. 117 to 119. For ease of use, the measurement techniques are listed by agency in alphabetical order.

Costs of Measuring Congestion

The Bay Area Metropolitan Transportation Commission estimated the ten year life cycle cost of their proposed (design is in progress) Traffic Operations System for the 460 centerline miles of freeway in the network at $289 million. The ten year life cycle cost of the Congestion Management portion of the system was estimated at $99.4 million. The estimated cost includes methods used to reduce the amount of recurring congestion, including ramp metering and motorist information systems. The benefit/cost ratio for the congestion management portion is 4.65 to 1 which is smaller than the predicted benefit/cost ratio of nearly 7 to 1 for the entire Traffic Operations System (27).

Table E-1. Summary of Congestion Criteria Used by Selected Agencies

Name of Agency	Freeways		Arterials	
	Definition of Congestion	Measurement and Monitoring of Congestion	Definition of Congestion	Measurement and Monitoring of Congestion
Alameda County Congestion Management Agency (Hayward, CA)	Speed < 35 mph for ≥ 15 minutes	Travel time data using the floating car technique then converted to 1985 HCM LOS values annually.	LOS F using HCM chapters 8 and 11	Travel time data using the floating car technique then converted to 1985 HCM LOS values annually.
Bay Area Metropolitan Transportation Commission (Oakland, CA)	Speed < 35 mph for ≥ 15 minutes	Travel time using areawide acceptable values.	LOS F	Intersection LOS (no indication given whether delay or v/c ratio).
Bi-State Regional Commission (Rock Island, IL)	LOS C in 2005 Long Range Plan - LOS D in 2020 LRP	No measuring or monitoring needed.	LOS C in 2005 Long Range Plan - LOS D in 2020 LRP	No measuring or monitoring needed.
California Department of Transportation, District 4 (Oakland, CA)	Speed < 35 mph for ≥ 15 minutes	Travel time data using floating car technique. 3 cars used during full data collection periods. Directional counts are also made for 1 full week at least every 3 years.	v/c ratio exceeds 1.0	Directional tube counts (summarized by 1 hour intervals) for 7 days every three years.
California Department of Transportation, District 2 (San Diego, CA)	Speed < 35 mph for ≥ 15 minutes	Travel time data using floating car technique. Multiple cars used during the peak period. Also loop detectors used for ramp metering.	None	None
Capital District Transportation Committee (Albany, NY)	> 1500 vph/lane which is LOS E	Travel times over the network obtained by modeling using TMODEL2.	Varies from 800 vph/lane to 1200 vph/lane(1)	Intersection delay calculated with number of lanes, generalized cycle length, and volume.
Chicago Area Transportation Study (Chicago, IL)	Presence detector occupied ≥ 30% which equals LOS E	Measurement obtained via the traffic surveillance system. Propose future measurement using minute-miles of delay.	v/c ratio exceeds 1.0	Measurement is project/location specific. Local agencies collect necessary turning movement counts. No continuous measurement program
Charlotte Department of Transportation (Charlotte, NC)	24 hour volumes > 66,000 vpd - 2 lane 90,000 vpd - 4 lane 120,000 - 6 lane	Traffic counts made by North Carolina DOT. The Charlotte DOT does not measure freeway congestion.	v/c ≥ 0.85 is unacceptable	All signalized intersections counted for a 12-hour period from 7 am to 7 pm.

Table E-1. Summary of Congestion Criteria Used by Selected Agencies
(Continued)

Name of Agency	Freeways		Arterials	
	Definition of Congestion	Measurement and Monitoring of Congestion	Definition of Congestion	Measurement and Monitoring of Congestion
Contra Costa County Transportation Authority (Walnut Creek, CA)	Speed < 35 mph for ≥ 15 minutes	Travel time data are collected using the floating car technique annually. Peak direction counts are also collected.	LOS F	Delay measured using 1985 HCM. Manual Traffic counts are also made annually.
Los Angeles City Metropolitan Transportation Authority (Los Angeles, CA)	LOS E or the current level, whichever is worse.	Corridors are identified as congested by their v/s ratio.	LOS E or the current level, whichever is worse.	V/C ratio calculated using the Intersection Capacity Utilization method and then converted to LOS.
New York Department of Transportation (Albany, NY)	LOS E	Vehicle hours of delay based on current volumes.	LOS E	Vehicle hours of delay based on current volumes.
North Carolina Department of Transportation (Raleigh, NC)	LOS D	The Florida DOT procedure is used for determining LOS. Measure average speed and volume counts.	LOS D	Measured using v/c ratios.
Puget Sound Regional Council (Seattle, WA)	LOS F	None		V/c ratio and delay are both used to measure congestion. Each city selects its own method. Turning movement counts are the most common form of data.
Riverside County Transportation Commission (Riverside, CA)	LOS E or the current level, whichever is worse.	Data provided by CALTRANS District 2.	LOS E or the current level, whichever is worse.	V/C ratio calculated using the Intersection Capacity Utilization method and then converted to LOS.
San Diego Association of Governments (San Diego, CA)	LOS D - RGMS(1) LOS E - CMP(2)	Measured using 1985 HCM procedures.	LOS D - RGMS(2) LOS E - CMP(3)	LOS based on section speed including intersection delay using simplified HCM method. LOS determined for heaviest travel direction for highest peak hour.

Table E-1. Summary of Congestion Criteria Used by Selected Agencies
(Continued)

Name of Agency	Freeways		Arterials	
	Definition of Congestion	Measurement and Monitoring of Congestion	Definition of Congestion	Measurement and Monitoring of Congestion
San Joaquin County Council of Governments (Stockton, CA)	LOS E	LOS values calculated using Florida LOS procedure annually. Counts obtained from DOT district office.	LOS E	Local jurisdictions must complete traffic counts annually. Florida LOS procedure used to calculate LOS values.
Santa Clara County Congestion Management Agency (San Jose, CA)	Speed < 30 mph for ≥ 15 min	Uses travel time data provided by CALTRANS District 4 annually.	LOS F	Each city must report LOS values for 150 to 170 intersections. Both mechanical and manual intersection counts are made annually.
Southwest Washington Regional Transportation Council (Vancouver, WA)	v/c > 0.90	Peak direction volumes measured. Capacities used are acceptable volumes based on functional class, number of lanes and typical conditions.	v/c > 0.90	Peak direction volumes measured. Capacities used are acceptable volumes based on functional class, number of lanes and typical conditions.
St. Cloud Area Planning Organization (St. Cloud, MN)	LOS D	None	LOS D	Mechanical 15-minute directional counts made annually at 200 locations. About 100 also made by MN DOT.
Washington Department of Transportation (Olympia, WA)	LOS D	Spot speed, average running speed, midblock volumes, turning movements, and intersection delay are all used somewhere in the state.	None Yet	Spot speed, average running speed, midblock volumes, turning movements, and intersection delay are all used somewhere in the state.

(1) Surface Street congestion defined as: Roadways with one lane each direction: > 800 vph/lane, LOS
    Multiple lane arterials: >1000 vph/lane, LOS B
    Multiple lane, limited access arterials: > 1200 vph/lane, LOS E
(2) RGMS - Regional Growth Management Strategy LOS applies to all state highways and the Regional Arterial System identified in SANDAG's Regional Transportation Plan.
(3) CMP - Congestion Management Program LOS applies to the designated CMP highway system and CMP designated principal arterials.

The Alameda County CMA contracted with a private consultant to perform a travel time study to measure the initial congestion levels in their network. The Original study (November 1991) cost $25,000 and covered 370 route kilometers (230 route miles) (740 directional kilometers or 460 directional miles). This translates to a fixed cost of $67.6 per route kilometer ($108.70 per route mile) or $33.8 per directional kilometer ($54.35 per directional mile). The most recent study (October 1992) cost $17,000. The Santa Clara County CMA estimates that intersection turning movement counts cost between $300 to $400 per intersection. This cost includes the tube costs to establish the peak 60-minute period and the manual turning movement counts.

The Capital District Transportation Committee (New York) reported a cost of $600 per intersection for manual turning movement counts made during 2-hour peak periods in both the morning and the evening. This includes making the counts, data reduction, and preparation of reports. The data processing is fully automated, with the field data entered directly to a PC for calculations using the HCM software.

No other agencies reported any congestion measurement cost data.

Agency Comments

Many agencies had specific ideas regarding how congestion management activities should be structured, including what they thought would work and what would not. The following comments were made by representatives of the various agencies relative to measuring congestion during the interview process.

- LOS is not a good measure of congestion (specific statement of Mr. Robert K. McCleary of the Contra Costa Transportation Authority). All of the executive directors of the CMAs in California (except the San Joaquin CMA) expressed similar views and pointed out their dissatisfaction with LOS as the performance measure for use in congestion management systems. The county CMAs in California have initiated a joint state-wide study on the use of LOS and other performance measures for measuring and monitoring congestion. The study is being managed by the Los Angeles County Metropolitan Transportation Authority and findings are expected to be available in April 1994. The study is being conducted by the COMSIS Corporation. CALTRANS, District 4 has found that average vehicle speed, obtained using the floating car method, is superior to volume-to-capacity ratio for the evaluation of congestion on their 805 kilometers (500 miles) of freeways. This position was supported in a very strong manner by the Alameda County Congestion Management Agency.

- The Los Angeles County Metropolitan Transportation Authority feels that LOS is, at best, a limited measure of congestion. It allows better decisions by the public bodies, but it is limited to the highway mode. Multiple levels of LOS F (F(0), F(1), F(2) and F(3)) are used to quantify the freeway segments in the Los Angeles Freeway system. The LOS F target is adequate for identifying the congested roadway

segments, but it is not descriptive enough to be used in the selection of particular projects.

- The Southern California Association of Governments feels that congestion is better defined by vehicle-hours of delay. It is a much broader definition and can be translated into real dollars for comparative purposes.

- The San Diego Association of Governments noted that LOS guidelines are difficult to use since the data requirements are extensive. San Diego AOG prefers that LOS be based on average travel time.

- The San Joaquin County Council of Governments feels that the most appropriate descriptor of urban congestion is still LOS. Their reasoning is that LOS is simple to use and understand, which is especially helpful for staff turnover. Measures of congestion such as spot and average running speed, midblock volumes, intersection turning movements, durations of congested flow, and intersection delay "may" be adequate to identify and plan congestion management projects. However, they still feel LOS is the most appropriate descriptor.

- The Washington DOT suggests speed and reduced personal trip delay in a corridor (product of occupancy and delay) as descriptors of urban congestion.

- Public officials have difficulty understanding that congestion can be measured in different ways (i.e. delay, v/c ratio) and that different LOS results can be achieved depending upon different assumptions and/or conditions (i.e. saturation flow rate, cycle length, etc.). Recommendations based on LOS results is a very politically charged issue in many communities.

- The Riverside County Transportation Commission feels that vehicle kilometers of travel (VKT) (vehicle miles of travel (VMT)) is a better measure of congestion than V/C ratios. The V/C ratio is difficult to calculate, especially with trip reductions. The V/C ratio can also be very complex to explain. A given V/C ratio may indicate LOS C when the roadway condition actually is LOS F. This makes is difficult to explain LOS to local elected officials. Another problem with V/C ratios is that it is very difficult to get accurate count data from the state. Frequently, the calculated V/C ratios are not based on current measurements. They are extrapolated from data several years old.

- The Contra Costa County Transportation Authority stated that the California legislation overestimates the availability of extensive traffic data (freeway and arterial data). The evaluation of roadways (freeways and arterials), and the resulting LOS, is a very politically charged issue. Some residents do not want their community to grow. To discourage growth, these people oppose the upgrading of roadways having the potential of increasing traffic within their community. Other citizens are

advocates of an expanding city. Heated debates occur regarding the criteria used in assigning LOS grades.

- The Bay Area Metropolitan Transportation Commission stated that common traffic data such as spot speed, average running speed, midblock volumes, intersection turning movements, duration of congested flow, and intersection delay are not adequate to identify and plan congestion management projects.

- The goal of the Alameda County Congestion Management Agency is to measure area wide congestion, not congestion at point locations. Therefore, delay and v/c ratio studies are not done at individual intersections. In particular, the LOS measures do not include the transit mode at all. Alameda County feels strongly that a better, more general measure of congestion is needed.

- The San Joaquin County Council of Governments stated that spot and average running speed, midblock volumes, intersection turning movements, duration of congested flow, and intersection delay "might" be adequate to identify and plan congestion management projects. LOS is the only performance measure considered by the San Joaquin County COG.

- The Los Angeles County Metropolitan Transportation Authority reported the ICU method of measurement was chosen due to its compatibility between cities within the LACMTA region.

- The Southern California Association of Governments felt that vehicle-hours of delay is the best measure of congestion.

- CALTRANS-11 stressed that there is a great need to increase funding of congestion management data collection projects.

- The San Diego Association of Governments (as well as most other California CMAs) felt that LOS guidelines are difficult to use due to the extensive data requirements. The data currently used to evaluate congestion of principal arterials are inadequate. SANDAG believes that peak period effective green time to cycle length (g/C) ratios are necessary to calculate intersection delay.

- The Washington DOT stressed that the data collection requirements must be flexible enough to allow the adaptation of the measuring system to fit the goals and objectives of the agency. Two suggested descriptors of urban congestion are speed and personal trip delay.

- The Denver Regional COG feels that traffic operations professionals have "fostered" LOS on the public. Other performance measures are more meaningful and better understood by public (ie travel time, speed). In the Denver area, none of the non-technical people favor the use of LOS. Traffic operations engineers with planning

experience, transportation planners and engineers and urban planners repeatedly had the same anti-LOS view as the non-technical people. Only traffic operations engineers with no planning experience and technicians concerned with small intersection projects favored use of LOS. Other performance measures which have been suggested as more meaningful include: average travel time, average speed over a section, spot speed, 24 hour speed profile, and v/c ratio.

Findings

The state-of-the-practice of congestion measurement suggests that there are many methods used to measure congestion. The most commonly used measure is Level-of-Service. This is probably the result of two factors: First, the California congestion legislation requires LOS in their CMS programs. Second, traffic operations personnel are commonly assigned the responsibility for the CMS program within an agency. Operations personnel are very familiar with intersection LOS analysis and tend to propose its use for measuring and monitoring congestion.

Table E-2 indicates the research staff view of the relationship between the measures of congestion being used and the applicable area. The area classifications are spots, corridors, and regions or subregions. Due consideration should be given to transit, trucking and ferry modes (where applicable) in selection of the measure of congestion to use. A more detailed table exploring the potential measures of congestion is included in Appendix B, Methods for Defining and Measuring Congestion.

The consensus of those who have considered the problem of determining an area wide measure of congestion is that LOS is not an adequate measure of area wide multi-modal congestion. There are three basic reasons for this opinion. First, LOS is point oriented and it is difficult to integrate the point LOS values into an area wide measure of congestion. Second, the LOS determination is based on a number of assumptions and computational techniques. This often results in different levels-of-service for the same roadway location. For example, using a different cycle length can change the LOS from F to D at a particular location. Third, the problem of projecting LOS to predict future congestion must be considered. There is no known method by which the turning movements for calculation of vehicular delay can be forecast with any degree of reliability. Since ISTEA requires projection of future congestion levels, it is concluded that LOS is not acceptable as a measure of area wide congestion. Moreover, LOS is limited to the vehicular highway and street transport mode and is not applicable to person mobility involving the automobile and public transit. Thus, LOS cannot be used as a multimodal or mobility based performance measure for congestion management.

The MPOs should adopt a measure of congestion consistent with the issues encountered in their region and use it uniformly throughout their area of responsibility. The recommended measure of congestion is travel rate (that is, minutes per mile or kilometer). Travel rate has the advantage of being relatively easy to determine, normally distributed, easy to integrate into a area wide measure of all modes, and sensitive to the changes in

Table E-2. Potential Measures of Roadway Congestion

Measure of Effectiveness	Application			
	Spot	Corridor	Areawide	Forecast Congestion
Level of Service	X			
Lane-Miles at LOS "X"		X	X	
VMT at LOS "X"		X	X	
Average travel speed		X		
Spot speed	X			
Average travel time[1]		X		X
Average travel rate[2][1]		X	X	X
Travel time contours[1]			X[4]	X
Total delay	X			
Excess delay	X	X	X[5]	
Average delay per vehicle/per person	X			
Delay/Incident	X			
Delay/VMT				
Delay/Trip		X		
Delay Due To Construction	X	X		
Volume, flow rate	X			
Volume/Capacity ratio	X			
Midblock Volume/Capacity Ratio[3]	X			
Volume/"Acceptable Flow Rate"	X	X	X	X
Suggested Congestion index[3]		X	X[5]	X[3]
Roadway Congestion Index		X	X	X
Minute-Miles Of Delay				
Detector occupancy	X			
Queue Length and Duration	X			
Acceleration Noise	X			
Accident Rates	X	X	X	
Percent of VMT By Functional Class		X	X	
VMT/Lane-Mile		X	X	
Person/Hour	X	X	X	X
Persons/Vehicle	X	X	X	
ODOT Level Of Capacity	X	X	X	X

1 mile = 1.609 kilometers

(1) Also applicable to transit.
(2) Minutes per mile or kilometer.
(3) Congestion Index: Midblock volume divided by a flow rate which represents acceptable traffic volume conditions for the type of roadway (i.e., 2-lane, 4-lane, 4-lane divided, intersection configuration, traffic control, etc.) may be vehicle per hour or vehicles per day.
(4) Limited application since a travel time contour map relates a specific origin and there is no procedure for aggregating trips.
(5) A weighted average (weighted by vehicle-miles of travel or vehicle kilometers of travel) can be used to obtain subarea or an area wide measure. The weighted average is similar to the Roadway Congestion Index (See Appendix B).

congestion levels. That is, the travel rate increases as the congestion level gets worse. This performance measure is especially appropriate for larger urban areas with mature transit systems.

Use of a volume to "acceptable flow" ratio is suggested as an alternative performance measure for small and medium sized urban areas where there is limited transit potential (less than 5% of person-trips by transit) and there is no transit oriented focal points (such as a University).

While an area wide measure of congestion is desirable, in some instances the differences between subareas within the metropolitan area may tend to mask the true effects of congestion. For example, if there are five subregions two of which have a high level of congestion and three have relatively little congestion, the single performance measure may very well indicate an acceptable level of congestion on the average. Subdividing the metropolitan area into a few relatively homogeneous subregions may well yield a better perspective of the congestion situation in the metropolitan area for the purpose of defining the congested areas of the community.

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APPENDIX F

STATE-OF-THE-PRACTICE: DEFINING CONGESTION

All references cited in large underlined numbers in this Appendix are identified in the References section beginning on page 29 following Chapter 3. Those identified in small numbers are references within this appendix and are located on page 130.

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Congestion is universally defined as the point when free flow conditions cease to exist. The problem is not with defining congestion. The problem is with defining the level of undesirable congestion. Conditions which are acceptable in a metropolitan area with a population of, say, 2-million are different than an area with an urban population of, say, 200,000. Furthermore, there is a difference between older cities which developed prior to the advent of the automobile and those which have developed with the auto. Thus, the definition of the undesirable level of congestion for each metropolitan area will vary.

Congestion is defined as "the level at which transportation system performance is no longer acceptable to the traveling public due to traffic interference." The level of acceptable system performance may vary by type of transportation facility, geographic location and/or time of day." (3, §500.503, p.12120)

Once a measure of congestion has been selected, an undesirable level of congestion based on that measure can be selected. Most agencies contacted indicated their chosen level of undesirable congestion. These congestion levels vary from agency to agency depending on local conditions. The level that smaller metropolitan areas generally consider to be undesirable congestion is usually acceptable to large metropolitan areas.

State-of-the-Practice for Freeways

All designated congestion management agencies in California are required by State Law to define congestion in their network by LOS. The governing legislation does not specify the acceptable level of congestion, nor does it mandate the methodology to be used to evaluate network segments. Each agency is free to choose the LOS values for defining congestion in their own network.

The majority of California sites define freeway congestion as a speed of less than 55 km/h (35 mph) for longer than 15 minutes, which corresponds to LOS F (Santa Clara County CMA uses 50 km/h (30 mph)). Facilities which were at LOS F when the congestion management program was initiated are "grandfathered" at LOS F. That is, even though acceptable congestion might be LOS E, congestion on these roadways might get worse as LOS F is the poorest LOS classification (i.e. there is no "LOS G"). The Santa Clara County CMA set a goal of LOS D for all member agencies, but the agencies are only required to conform to their standard of LOS F (3).

The exceptions to this definition are the Los Angeles Transportation Commission, and the San Joaquin County CMA which define congestion only by LOS. They defined freeway congestion as LOS E or the current level, whichever is worse. The San Joaquin County COG uses average weekday volumes and the Florida Method for determining LOS (13).

Another exception is the Riverside County Transportation Commission. They established a two-tired approach for defining the acceptable level of congestion. Tier 1

involves the locally established minimum, while tier 2 involves the CMP minimum. Most local agencies within the county have established LOS C or D as the minimum level of acceptable congestion. Thus, LOS D or E indicates congested conditions. For the CMP, the minimum LOS standard is LOS E or the current level, whichever is farthest from LOS A. Therefore, the local communities set a goal of LOS C or D for their roadway system to maintain an efficient and effective transportation system. However, in order to not lose state funding, the CMP definition of congestion is set much lower at LOS E (11).

One other exception in California is with the San Diego Association of Governments (SANDAG). They define congestion as LOS D for their Regional Growth Management Strategy (RGMS) and LOS E for their Congestion Management Program (CMP). The RGMS definition applies to all state highways and the regional arterial system as defined in SANDAG's Regional Transportation Plan. The CMP definition applies to the SANDAG designated CMP highway system including all state highways and CMP principal arterials. Local planning and project mitigation will attempt to achieve RGMS levels (12).

The Bi-State Regional Commission (Illinois and Iowa) defines congestion as LOS C or D. In their 2005 long range plan, congestion was defined as LOS C, while in the 2020 long range plan, congestion was defined as LOS D. Congestion is not viewed as a serious problem and the region is an air quality attainment area. Congestion is largely restricted to the Mississippi River bridges and occurs as a result of maintenance, traffic incidents, and weather.

The St. Cloud Area Planning Organization in Minnesota currently defines congestion as LOS D using the *1985 Highway Capacity Manual*. It is expected that this value will change to LOS E in the future. The St. Cloud Area Planning Organization also does not experience the major congestion problems and only monitors arterial streets. They have defined freeway congestion (IH-94 which passes through the western edge of the MPO) to be LOS D, but they do not measure, monitor, or experience congestion problems on the freeway.

The Chicago Area Transportation Study (CATS) defines congestion according to the Illinois Department of Transportation procedure utilizing their extensive network of loop detectors. Congestion is defined as a presence detector occupied at least 30% of the time. This occupancy rate corresponds to LOS E. Hence, acceptable congestion is an occupancy rate of less than 30% (LOS D), which is also a v/c ratio of less than 1.0. Free flow conditions exist when loop occupancies are less than 20%, as illustrated in Figure F-1. Between 20 and 30%, traffic conditions begin to deteriorate with congestion impending. Congested conditions exist when the detector occupancy is greater than 30% ([1,2]).

The New York Department of Transportation defines congestion as LOS E on both freeways and arterial streets, measured using excess vehicle hours of delay as previously described. The Capital District Transportation Committee (Albany, New York) defines congestion on freeways as volumes greater than 1500 vph/lane which they use as corresponding to LOS E.

Figure F-1. Freeway Conditions Based on Loop Occupancy
SOURCE: Reference (38)
1 mile = 1.609 kilometers
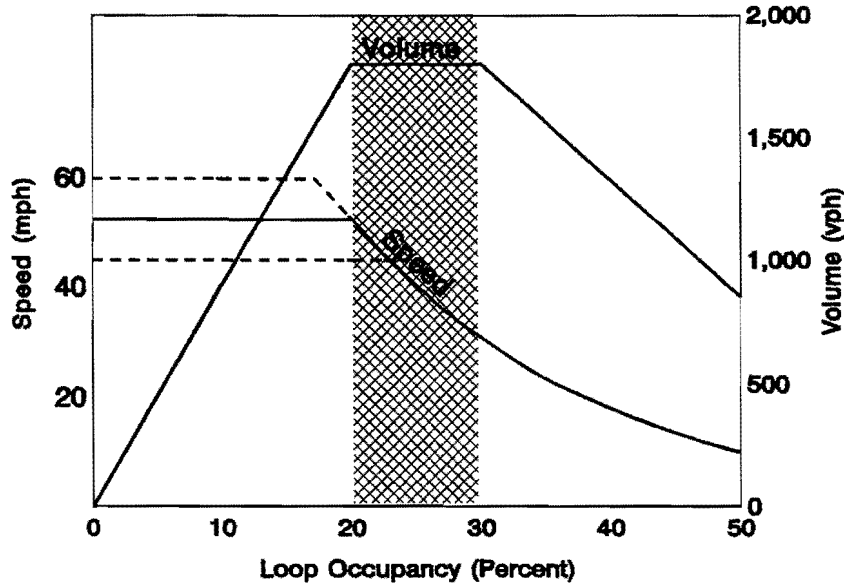
The Washington Department of Transportation has not yet defined congested flow for the state congestion management system, but they reported that they anticipate using LOS. Currently the DOT uses LOS D as congestion on rural freeways and HOV lanes and LOS E as congestion for urban freeways. They have encountered problems with defining LOS for ferry operations and are considering using the number of vehicles which cannot board and must wait for the next ferry as a criterion for LOS of the ferry routes. Many cities in the Seattle area have opted to allow the level of congestion to get worse in order to encourage transit usage, bicycle use, and walking.

The Puget Sound Regional Council in Seattle uses LOS F as the definition of congestion on the Seattle area freeway system. The Southwest Washington Regional Transportation Council in Vancouver defines congestion as a v/c ratio greater than 0.90, which corresponds to LOS E. This definition is identical for both freeways and arterial streets.

The North Carolina DOT defines congestion on freeways as LOS D or worse. LOS is determined using the Florida DOT procedure. The Charlotte Department of Transportation defines freeway congestion using volumes during a 24 hour period, as supplied by the North Carolina DOT. Congested conditions occur when the freeway surpasses the following volumes: For a 2-lane freeway, >66,000 vpd; for a 4-lane freeway, >90,000 vpd; and for a 6-lane freeway, >120,000 vpd. Plans for the future include a change to volumes for a 2 hour morning period instead of a 24 hour period, probably from 7 to 9 am.

The Denver Regional COG, Pikes Peak COG, and Colorado DOT have a joint effort to investigate several CMS issues. Among them is the issue of defining congestion. A conclusion has not yet been reached in this regard, but the impression is that a common definition of acceptable/unacceptable congestion cannot be agreed upon. The hope is that the same measure of congestion can be used in all areas, but each agency will define their unacceptable level of congestion differently.

All of the definitions used by various agencies in describing freeway congestion are summarized in Table E-1, pp. 114 to 116. For ease of use, the measurement techniques are listed by agency in alphabetical order.

State-of-the-Practice for Arterial Streets

As required by state law, designated congestion management agencies in California must define arterial street congestion in their network by LOS. The Alameda CMA, Contra Costa County TA and Santa Clara County CMA, as well as the Bay Area MTC (the MPO for the San Francisco Bay Area), define arterial street congestion as LOS F. Each of these agencies measures congestion differently, but all measures are converted to LOS values in order to be in compliance with state law. The Los Angeles County MTA, Riverside County TC, and San Joaquin COG define arterial street congestion as LOS E or the current level, whichever is worse. CALTRANS-4 in Oakland (which is not a designated congestion management agency) defines arterial street congestion as a v/c ratio greater than 1.0. CALTRANS-11 in San Diego has not defined arterial street congestion since the agency does not monitor arterial streets. The measures used to calculate LOS for the California agencies are identified in Table E-1, pp. 114 to 116.

The Bi-State Regional Commission (Illinois and Iowa) defines arterial street congestion as LOS C or D. In their 2005 long range plan, congestion was defined as LOS D, while in the 2020 long range plan, congestion was defined as LOS D. Congestion is not viewed as a serious problem since the region is an air quality attainment area. Congestion is largely restricted to the five Mississippi River bridges (2 interstate and 3 arterial) and occurs as a result of maintenance, traffic incidents, and weather.

The St. Cloud Area Planning Organization in Minnesota currently defines congestion as LOS D using the *1985 Highway Capacity Manual*. It is expected that this value will change to LOS E in the future. The St. Cloud Area Planning Organization does not experience major congestion problems, but chose a lower LOS value as the level of undesirable congestion than the Bi-State Regional Commission.

The Chicago Area Transportation Study (CATS) defines surface street congestion as a v/c ratio greater than 1.0, which they correspond to LOS E. Acceptable congestion is a v/c ratio of 1.0 or less.

The New York Department of Transportation defines congestion as LOS E on both freeways and arterial streets. The Capital District Transportation Committee in Albany,

New York, also defines congestion as LOS E, but this LOS designation is defined differently for different roads. For example, typical capacities are: roadways with one lane in each direction, LOS E is defined as a volume greater than 800 vph/lane; for multiple lane arterials, LOS E is defined as a volume greater than 1000 vph/lane; and for limited access multiple lane arterials, LOS E is defined as a volume greater than 1200 vph/lane. These definitions of "acceptable capacities"/congestion are used in network modeling (using TMODEL2) to determine the condition of roadways within the network.

The Washington Department of Transportation has not yet defined congestion for arterial streets. As on freeways, many cities in the Seattle area have opted to allow the level of congestion to deteriorate in order to encourage transit usage, bicycle use, and walking. The Puget Sound Regional Council in Seattle uses both v/c ratio and delay to define congestion on surface streets. Different cities and counties in the regional council choose their own definition of congestion, and the Puget Sound Regional Council accepts the definition selected by each city.

The North Carolina DOT defines arterial street congestion as LOS D or worse. This, in turn, is defined as an average speed of less than 27 km/h (17 mph) for urban arterials and a delay of greater than 25.1 seconds at intersections (28). The Charlotte DOT defines arterial street congestion using v/c ratio of the critical movements for each signalized intersection within the city. Congestion is defined as the following (26):

Critical v/c $\geq$ 1.10 is severe congestion
Critical v/c $\geq$ 0.95 is high congestion
Critical v/c $\geq$ 0.90 is marginal congestion
Critical v/c $\geq$ 0.85 is congestion

Twenty-four hour traffic volumes are also used to identify congested surface streets. Congested conditions occur when the surface street surpasses the following volumes: For a 2-lane street, >17,000 vpd; for a 4-lane street, >33,000 vpd; and for a 6-lane street, >49,000 vpd. Plans for the future include a change to volumes for a 2 hour morning period, probably from 7 to 9 am.

All of the definitions used by various agencies in describing arterial street congestion are summarized in Table E-1, pp. 114 to 116. For ease of use, the measurement techniques are listed by agency in alphabetical order.

Findings

The level of traffic interaction at which congested operations begins is commonly defined as LOS D, E or F. LOS E and F definitions are mainly used in large metropolitan areas where higher levels of congestion are accepted by the travelling public. The LOS D definition is used in small metropolitan areas where better operating conditions are possible.

As previously stated, LOS does not integrate directly to an areawide level of service, especially when intersection LOS is used. Nearly all agencies interviewed expressed dissatisfaction with using LOS as the measure of congestion (See Chapter 2). Other

measures of congestion are more applicable for use in a CMS. Therefore, a recommendation of the definition of congestion based on LOS is not practical. A different measure of congestion must be used in defining congestion in order for CMS implementation to be effective.

Consistent with the travel rate recommendation for measuring congestion, an increase in travel rate would indicate congested operation. The recommended travel rates for congested conditions are shown in Table F-1.

Table F-1. Recommended Travel Rates for Congested Conditions

	Level of Congestion*	Travel Rate (minutes/mile)	
		Highway	Transit
Freeways or Transit on separate ROW	Moderate	1.3	1.3
	Heavy	1.7	1.7
Arterial Streets: 70 km/h (45 mph) Posted Speed	Moderate	1.7	3.7
	Heavy	2.0	4.0
Arterial Streets: 55 km/h (35 mph) Posted Speed	Moderate	2.4	4.4
	Heavy	3.0	5.0

*Moderate Congestion - Average running speed 16 km/h (10 mph) below posted speed for a period of 15 minutes or more.
Heavy Congestion - Average running speed of 24 km/h (15 mph) or more below posted speed for a period of 15 minutes or more.

The measurement should be made over homogeneous geometric situations of more than 1.6 kilometer (one mile) and less than 8 kilometers (five miles) in length. The integration of the section travel rate into an areawide measure of congestion should be based on the weighted average travel rate in the defined network.

$$\textit{System Wide Travel Rate} = \frac{\sum t_i L_i T_i + \sum (t_i + tTER_i) L_i R_i F_i}{\sum L_i T_i + \sum L_i R_i F_i}$$

Where: t_i = travel rate on street section i
$tTER_i$ = Transit Terminal time (½ of transit headway with a maximum of 5 minutes)
L_i = length of section i (miles or kilometers)

T_i = ADT in section i

R_i = ridership on transit vehicle in section i

F_i = frequency of bus service (buses/hour) in section i

Note: The $(t_i + iTER_i)L_iR_iF_i$ term can be used for transit or separate right-of-way, if t_i is the travel rate on the transit section.

This system wide travel rate is compared to the weighted average travel rate from Table F-1. The system average travel rate value can be for either moderate or heavy congestion. However, they cannot be mixed in any single computation. A calculated value greater than the tabular value suggests that the system is congested or near congested operation.

APPENDIX F REFERENCES

1.   J.M. McDermott, "Freeway Surveillance and Control," *Transportation Engineering Journal,* American Society of Civil Engineers, Vol.106, No. TE3, May 1980.

2.   J.M. McDermott, S.J. Kolemko, and R.J. Wojcik, *Chicago Area Expressway Surveillance and Control: Final Report,* Illinois Department of Transportation, March 1979.

3.   *U.S. 70 Corridor Study, Hickory-Newton-Conover Urban Area,* Statewide Planning Group, Municipal Traffic Engineering Assistance Program, North Carolina Department of Transportation, November 1990.

APPENDIX G

STATE-OF-THE-PRACTICE:
NETWORK DESCRIPTION

All references cited in large underlined numbers in this Appendix are identified in the References section beginning on page 29 following Chapter 3.

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State-of-the-Practice for MPOs and CMAs

Several agencies described quantitative criteria or procedural processes for identifying their network during the interview process. Several agencies established specific criteria for identifying the network. Others used (or proposed to use) their urban transportation planning network as the basis for the CMS network, while some had not yet given much attention to how the CMS network would be defined.

The Contra Costa County Transportation Authority (CCTA) has designated the CMS network as either routes of regional significance or basic routes. Routes of regional significance are those roadways which typically carry high traffic volumes and connect the various parts of Contra Costa County or link the county with another county. Routes of regional significance are identified by the CCTA in cooperation with local jurisdictions. Freeways and major arterials designated as routes of regional significance account for the majority of serious congestion problems in the county. Basic routes are identified by local jurisdictions and are all major roads not classified as routes of regional significance.

The Alameda County CMA identified a network of 370 route kilometers (230 route miles) including 185 kilometers (115 miles) of freeways, 142 kilometers (89 miles) of state highways (other than freeways) and 41 kilometers (26 miles) of city/county principal arterials. The identified network carries 72% of the VKT (VMT) carried county wide (5). These facilities which comprise the Alameda County CMS network were identified as follows:

1. All route segments/links in the traffic assignment network were arranged in descending order of volume.
2. The VKT (VMT) on each link and total VKT (VMT) were calculated.
3. Beginning with the highest volume link and progressing down the list of links arranged in descending order of value, summation of VKT (VMT) continues until it equalled 70% of the total VKT (VMT). In effect, all links with an ADT of 30,000 or more were included.
4. The network thus identified was reviewed for continuity, and "missing" links were added to provide reasonable continuity.

The Alameda County Network is shown in Figure G-1.

The network defined in the Santa Clara Congestion Management Program (8) includes both freeways and principal arterials and stresses continuity between segments. A principal arterial is defined as a roadway which connects to the county freeway system or meets one of the following criteria:

1. All state highways,
2. All 6-lane facilities,
3. Most 4-lane roadways,
4. Roadway sections necessary to provide continuity, most of such facilities have an ADT at least 30,000 vpd.

The Santa Clara County CMA anticipates that when new or current roadways meet traffic volumes and the other criteria, these roadways will be added to the network. The Santa Clara County Network is shown in Figure G-2.

The 1991 San Joaquin County CMP identified 14 principal arterials and 11 state highways. In general, these designated roadways correspond to those chosen by adjoining CMP counties (Alameda, Contra Costa, Sacramento, Stanislaus). This network is evaluated on an annual basis to determine if additional routes need to be added (It should be recalled that the California legislation allows elements to be added to the CMS network, but not removed). Principal arterials were defined as those roadways with the following characteristics (18).

1. Principal arterials are used for travel between cities, across metropolitan areas or between key trip generators. They also include key access roads to the downtown areas or central business districts and east-west routes that link the two primary north-south routes in the county.
2. Access on principal arterials is generally limited.
3. Traffic volumes on principal arterials vary, depending on the nature of the road (urban or rural), but generally these segments carry higher volumes than neighboring links.
4. Principal arterials are connected to other principal arterials or highways forming a comprehensive network rather than a collection of discontinuous routes.

The Los Angeles County Metropolitan Transportation Authority identified a network encompassing more than 1600 kilometers (1,000 miles), including 800 kilometers (500 miles) or freeway, 640 kilometers (400 miles) of state-maintained arterials, and 160 kilometers (100 miles) of locally-maintained arterials. The following criteria were used in identifying the selected routes (15):

1. All existing state highways (both freeways and arterials); and
2. Principal arterials defined as:
   a. Routes that complete gaps in the state highway system,
   b. Routes providing continuity with the CMP roadway networks in adjacent counties, and
   c. Routes along major inter-jurisdictional travel corridors, providing primary, high volume or multi-modal transportation.

Transit segments were included in the system only when the line segment ran parallel to a major transportation corridor or had the potential for reducing the travel demand within the corridor.

The Riverside County Transportation Commission identified a minimum number of roadways into their network in order to reduce the data collection costs. The following criteria were used in identifying the selected routes (16):

Figure G-1. Alameda County CMS Network
SOURCE: Reference (5), p. 2.

Legend:
- Interstate Highway/Freeway
- Other State Highway
- Principal Arterial
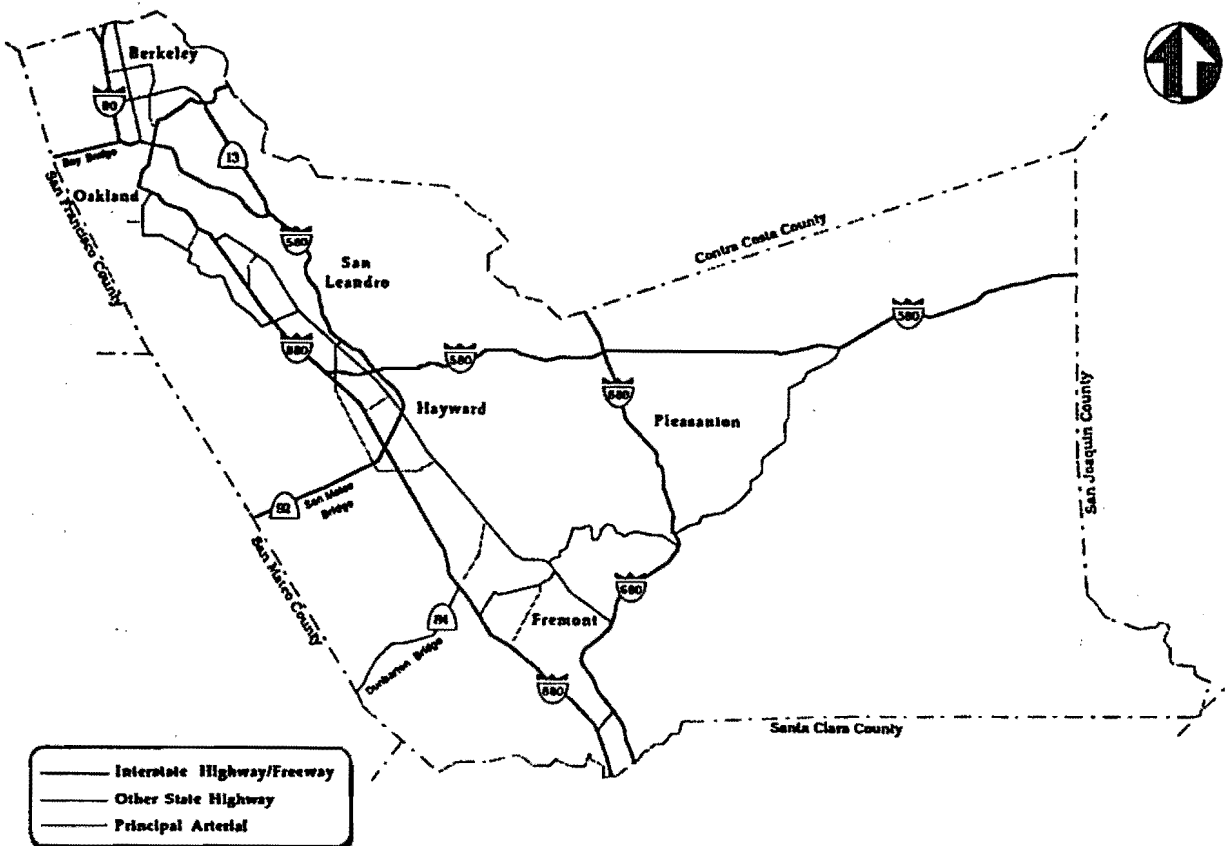
* As adopted by the Alameda County
Congestion Management Agency, October 24, 1991

Figure G-2. Santa Clara County CMS Network
SOURCE: Reference (8), p. 1-2.

1. All freeways,
2. All expressways,
3. Routes identified on CALTRANS "Functional Classification System" maps as "Principal Arterials,"
4. Facilities linking cities/communities and major activity centers,
5. Projects included in the Regional Mobility Element (RME),
6. Projects included in the Regional Transportation Improvement Plan (RTIP),
7. Planned facilities meeting the criteria established above which are to be implemented, improved or extended between 1992 and the year 2000, and
8. Consistency with networks developed in adjoining counties within the Southern California Association of Governments region.

CALTRANS-4 is not a designated congestion management agency so it has not identified a CMS network. However, CALTRANS-4 has responsibility for 840 kilometers (525 miles) of freeways in the San Francisco Bay Area. This network also includes 1361 kilometers (851 miles) of non-freeway state highways. CALTRANS-4 monitors this network on a regular basis and reports speed, volume, and other traffic data to requesting agencies within the Bay Area (28).

The Chicago Area Transportation Study (CATS) has not yet identified a specific network for monitoring congestion. However, the network would probably consist of all freeways, toll roads, and strategic regional arterials (of which there are 2170 kilometers (1350 miles)). The network is anticipated to be similar to the extensive network defined for "Operation Green Light" (OGL). The OGL project identified a network of Strategic Regional Arterials (SRA). The program involves a five year review of 2150 kilometers (1340 miles) of arterials.

During the first year, OGL developed preferred designs and a manual to be used for future reviews and analysis (37, 38). In addition, they reviewed 392 kilometers (245 miles) of SRA routes in detail, and the second year will involve reviews of 490 SRA kilometers (305 SRA miles). Each route analysis includes a corridor advisory group that includes representatives of communities along the route as well as business and special interest groups. An analysis of a network of routes which are important high volume routes but not SRA's will also occur. These routes will require significant operational improvements if they are to continue to function as major access roads to activity areas and commercial centers.

The Southwest Washington Regional Transportation Council defined a network based upon major travel corridors. These corridors were strongly influenced by the proximity to and economic connection with the much larger Portland urban area - specifically the two Columbia River bridges and by regional travel patterns. The network was largely based upon staff knowledge of the area and regional travel patterns. Although not specifically used as a criteria, the network generally includes road segments with an ADT of 20,000 or more. In selecting the network, "CMS was viewed as dealing with regional and through traffic more so than trips of moderate length" (24).

Several agencies have defined a network which they hoped would satisfy the ISTEA requirements, but did not report any selection criteria. The Washington Department of Transportation has designated all state highways and ferry routes outside the TMAs to be in their congestion management network. The Bay Area Metropolitan Transportation Commission identified 740 centerline kilometers (460 centerline miles) of freeway throughout the Bay Area as their network, and at the time of the site visit, arterial streets were not identified as part of the congestion management network.

The Capital District Transportation Committee (New York) had not yet defined a congestion management network at the time of the site visit. The current network used for planning purposes consists of all urban and rural roadways classified as arterials or collectors. This network is expected to comprise the base for the CMS network.

The San Diego Association of Governments' network comprises selected regionally significant arterial streets and roadways in addition to the state highway system. The system consists of 1105 kilometers (687 miles), including 477 kilometers (297 miles) of state freeways, 472 kilometers (294 miles) of conventional state highways, and 154 kilometers (96 miles) of urban principal arterials (12). Spacing and functional class were used as the basic selection criteria. Local governments were allowed to nominate arterial sections within their jurisdiction. The final decisions regarding the selected network were made by a task group composed of representatives from all interested parties.

The Charlotte DOT has not specifically identified a network for CMS. However, it is anticipated that the CMS network will be the same as that presently used for operations and transportation planning. This consists of the following: All freeways (109 centerline kilometers or 68 centerline miles), all major arterials (760 kilometers or 472 miles), all minor arterials (472 kilometers or 294 miles) and 462 kilometers (287 miles) of other streets. The system includes some 500 signals which are operated in 22 coordinated signal systems. Every signalized intersection within the corporate limits of the City of Charlotte is counted at least once every two years.

The Pikes Peak COG is planning to use the transportation planning/modeling network as the basis for their monitoring program. However, only those links in geographical areas nearing or exceeding air quality standards will be included in the CMS network. Thus, the CMS network will largely consist of the I-25 corridor, the US-24 corridor and an area south of the Air Force Academy and the north end of Academy Blvd.

State-of-the-Practice for State DOTs

The North Carolina DOT reported that the statewide CMS network will incorporate the MPO networks along with the remaining portions of the state. The CMS network will include those road segments which are currently congested plus those segments expected to become congested within the next 5 years. In addition, links will be added to complete a logical system with continuity.

The Washington DOT reported that they plan on using the State highway system as their CMS network. The three MPOs designated as TMAs will have the responsibility for a more detailed network within their jurisdiction. The State will have responsibility for all state highways and the MPO will be responsible for other roadways on the remaining network. Two additional MPOs in the State are not designated as TMAs, but they have the option of having their own CMS program if they wish. If they chose to create a CMS for their metropolitan area, the MPO will be responsible for the detailed CMS network within their jurisdiction and the Washington DOT will have the responsibility for the remaining State network.

The Arizona DOT is expected to incorporate the two TMAs (Phoenix and Tucson) into their statewide CMS network. The State CMS network is expected to include freeways, the national highway system, and some rural roads maintained by the Arizona DOT. The two TMAs will select a more detailed network for their metropolitan area and will assume responsibility for the network within their jurisdiction.

The New Jersey DOT currently has three MPOs that cover the entire State. Each of these MPOs will define a detailed CMS network for their jurisdiction. The State CMS network is expected to be composed of these three networks. The NJ DOT sees a strong role for the MPOs and will work with them to coordinate CMS activities and programs.

The Colorado DOT reportedly plans to use the national highway system outside of their TMAs as the State CMS network. The TMAs will define a detailed CMS network for their metropolitan area, and each of the TMA networks will become part of the statewide CMS network.

Observations

Designation of the CMS network is a major component in the implementation and administration of a congestion management system. This network forms the area for congestion measuring and monitoring activities and for implementing future congestion management techniques. The CMS network should be defined to include major freeways and arterial streets in a manor which will provide continuity between segments and also include transit, ferry operations, and other modes of travel which operate over or relate directly to the roadway network.

It is important to designate a complete and useful CMS network. The designated network should have appropriate continuity, but not to the extent that every high volume road or street is automatically included. Logic would suggest that most major roadways would be included in a CMS network. Criteria based on volume or VKT (VMT) has been used to help select network components. The National Highway System might be a logical base when identifying a state CMS network.

When selecting a network it should be remembered that each segment identified must be monitored on a regular basis. In addition, the network will be used to help identify

roadways and intersections that must be evaluated in the land-use impact analysis and to help identify candidate capital improvement program elements.

The modeling network used for forecasting volumes and future congestion needs to have extensive continuity. Also, it may well need to have a great deal more detail than the designated CMS network. Both the continuity and detail are necessary to achieve more realistic link loadings than those elements which are used in the CMS program.

Agency Comments

Many agencies had specific ideas regarding how congestion management activities should be structured, including what they thought would work and what would not. The following comments were made by representatives of the various agencies relative to defining the network during the interview process.

- The Alameda County CMA feels that their network is adequate for monitoring areawide congestion. However, a much more detailed network is needed for evaluating the impact of land use decisions and for addressing the various concerns of the municipalities.

- Concerning the size and scope of congestion management districts, the Los Angeles Transportation Commission feels that a regional approach would be best if the area is not too large. In the case of Los Angeles (over 1600 kilometers (1000 miles) of freeways and 9 million people), they suggest a two tired system. One tier for smaller metropolitan areas and one for the very large politically complex urban area.

- The Southern California Association of Governments feels there is a major problem in the definition of system elements between counties. Modification of the California Law is required to resolve these problems. The criteria selecting transport elements for the CMP system should be uniform enough that these conflicts cannot occur.

- The Washington Department of Transportation feels that, when defining a system, it is important for the CMS network to match what the MPO defines as a significant system. It must also be compatible with the air quality boundaries and system definition requirements.

- The North Carolina DOT representative stated that the Highway Performance Monitoring System (HPMS) is not an appropriate CMS network. The modeling process should be utilized to help identify the CMS network. The models could be used for identifying roadway segments that might be expected to become congested within 5 or 10 years. In addition, the NC DOT feels that there is no need to monitor a roadway segment until congestion is eminent (i.e. within 5 or 10 years). They feel these segments should not be included in the network until that time.

● The Colorado DOT representatives stated that the network used for the Highway Pavement Management System (HPMS) is not an appropriate CMS network.

Findings

The definition of a CMS network has a profound impact on the quality of the congestion management data and the cost of monitoring the system. For these reasons, the network should be defined in a very systematic and objective manner. Such a procedure for defining the CMS network follows.

1. Divide all freeway and arterial roadways in the agency's area of jurisdiction into segments of similar cross section.

2. Assemble the traffic volume data for each segment as defined in step 1.

3. Calculate the vehicle-kilometers (vehicle-miles) of travel on each segment.

4. Array the segments in descending order of VKT (VMT).

5. Determine the total VKT (VMT) on all segments.

6. Sum the VKT's (VMT's) until 70 percent of the area VKT (VMT) has been exceeded.

7. Review the resulting system to insure that there are no discontinuities in the designated system.

8. For transit routes on separate right-of-way, use Steps 1 through 7 to select the transit portion of the CMS network. Person-kilometers (person-miles) rather than vehicle-kilometers (vehicle-miles) should be used.

The resulting network will be objectively selected and representative of the entire metropolitan area. For these reasons, the network will be less subject to local pressures. The CMS network should be formally adopted by the metropolitan planning organization. Modifications of the network would thus only be allowed by a vote of the MPO.

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APPENDIX H

STATE-OF-THE-PRACTICE: MONITORING CONGESTION

All references cited with large underlined numbers in this Appendix are identified in the References section beginning on page 29 following Chapter 3.

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The initial measurement of congestion on each segment of the network will establish baseline congestion levels. Each segment in the network must then be monitored on a regular basis to update conditions and evaluate the effect of implemented strategies. Congestion levels can be monitored continuously or at designated time intervals.

Monitoring activities should coincide with updates of the CMP. The California legislation requires the designated CMAs to update their CMP every other year, but they must monitor congestion levels annually. Many agencies in California reported that they feel that the annual update requirement is a waste of funds since the CMP is updated only every other year.

The network and the measure of congestion selected for use in the CMS program must serve two essential functions. First, to objectively measure the level of congested operation; and second, to be suitable to allow projection of the probable congestion levels in the near term and distant future. This implies that the process of accumulating, evaluating, projecting, and storing the data for easy retrieval has been carefully and fully developed. If this has been accomplished, the monitoring program will be a routine activity.

The traffic monitoring program described in the *USDOT Traffic Monitoring Guide* (39) recommends sampling traffic volumes, vehicle classifications and truck weights and volumes required for the Highway Performance Monitoring System (HPMS). This monitoring system is specifically designed for the HPMS. The traffic volumes consist of 48-hour measurements systematically distributed throughout the year and across the State. One-third of these volumes are collected annually, so a complete data set is collected on a three year cycle. An emphasis is placed on collecting a representative sample throughout the state. For CMS applications, traffic monitoring should be completed on the defined CMS network; however, neither the data collection cycle nor the type of data may be appropriate for congestion management.

The *AASHTO Guidelines for Traffic Data Programs* (40) recommends that data collection should be completed on an annual basis. Random road segments should be selected to obtain a representative sample of data. These guidelines are intended to help establish a process for adoption of national traffic monitoring standards. However, for CMS applications, traffic monitoring activities should be completed throughout the defined network, not on a random basis. The interested reader is referred to the *USDOT Traffic Monitoring Guide* and the *AASHTO Guidelines for Traffic Data Programs* for more detailed information.

State-of-the-Practice for Freeways

The majority of counties in Northern California rely on CALTRANS-4 to monitor freeway congestion. Most use the CALTRANS-4 supplied data to evaluate the congestion levels on their freeways, but they generally do not place much emphasis on the actual

numbers. Some agencies commented on the deficiencies in the CALTRANS-4 data (principally time lag in receiving the travel time data).

CALTRANS-4 monitors congestion on a continuous basis. The traffic count program consists of 12 continuous count stations and 80 count stations which are operated 4 times per year (for both freeways and arterial streets). In addition, 12-hour classification counts are made at 20 locations each year. All freeway and freeway ramps are counted directionally for a full week (7 days) in one hour intervals on a 3-year cycle. All count data collected by CALTRANS-4 are available to anyone with access to the state data system. These peak hour counts, along with the practical capacity of a particular segment, can be used to determine the volume to capacity ratio of the segment for use in a CMP.

The Santa Clara County CMA requires that each city monitor LOS on each segment of the CMS network within their jurisdiction. After establishing baseline congestion levels, the monitoring activities must be completed on a fiscal year cycle. This allows the CMA to determine conformance and non-conformance areas to be included in the revised CMP which must be completed in June of each year. This time period coincides with the start of the fiscal year for Santa Clara County (8).

The Alameda County CMA is the exception in Northern California for using the CALTRANS-4 supplied data. The CMA does not utilize the data provided by CALTRANS-4 for several reasons. The CMA feels that CALTRANS-4 does not collect the data when the CMA wants or needs it, the data are not collected on all routes/arterials in the network, the data are not necessarily collected annually, and CALTRANS-4 does not have sufficient funds to do what the CMA needs.

The Alameda County CMA retains a private consultant to monitor congestion on both freeways and arterial streets. Travel time data are collected during the study period on a Tuesday, Wednesday, or Thursday afternoon during the peak hours of 4 to 6 p.m, as specified by the Alameda County CMP (5). The initial study which identified baseline congestion levels determined that 22 percent of the freeway system and 8 percent of the state highways and principal arterials were operating at LOS F during the peak period. These segments were not monitored during the subsequent study. Similarly, segments which were initially evaluated at LOS A and B were not reevaluated. Only roadway segments which were evaluated at LOS C, D, or E were monitored during the second study period to determine if conditions had improved, stayed the same, or deteriorated. The results of that study show that generally traffic conditions are similar to the previous year, but there was a slight improvement in speeds on the network (6).

The consultant recommended that the monitoring activities be completed in one of two time periods, from March to mid-May or from late September to mid-November. These time periods avoid the traffic fluctuations which occur during the winter rainy season and the summer vacation season. The consultant also recommended that a full study only be completed every other year, with a partial study completed on the year in between. The full study would involve monitoring conditions on all roadway segments within the Alameda

County CMP network, while the partial study would only involve roadways classified with LOS D, E, or F. It was noted that monitoring LOS A, B, and C classified roadways on a yearly basis is unnecessary since the segments would not deteriorate to congested conditions within a years time period (5).

The Alameda County CMA requires that LOS on the designated roadways be monitored by the cities annually and reported to the CMA by September 1 of each year (5). By reporting before September, cities have time to respond or react if there is a deficiency before conformance funding requests are due in October or November. However, this conflicts with the monitoring periods recommended by the consultant. The spring time period is too early for monitoring to report in September, and the fall period is past the deadline.

Annual monitoring periods for the other parts of the CMS have also been established in Alameda County. Attainment of transit standards must be reported to the CMA by September 1 of each year. By July 1 of each year, conformance with the trip reduction and travel demand management ordinances must be demonstrated. In addition, by August 1 of each year, conformance with the land use analysis program must be demonstrated, and by May 1 of each year, project lists for improving or maintaining the LOS must be submitted in accordance with the capital improvement program (5).

The Contra Costa County TA and the San Joaquin County COG rely on information provided by CALTRANS-4. Contra Costa County uses the travel time data. However, the data were reported to be collected during peak periods once a year, which does not agree with what CALTRANS-4 reported. The San Joaquin County COG uses traffic volumes for freeway segments within the county to monitor freeway congestion levels.

The Los Angeles County Metropolitan Transportation Authority has selected 70 key locations within the county to monitor congestion and quantify freeway system operation. The results of the monitoring activities are provided by CALTRANS. Monitoring locations are typically capacity-constraining areas such as near freeway ramp intersections. A maximum spacing between monitoring locations has been set at 3.2 kilometers (2 miles) for urban freeways. The spacing may be increased if traffic volumes and capacity are consistent over large distances. Monitoring activities must be performed on an annual basis in conformance with state law (15). All counts must be taken on at least two weekdays, except not on Monday, Friday, holidays, or when schools are not in session. In addition, counts must be completed during good weather in areas with no road construction or major traffic accidents. At a minimum, peak period counts must include two time periods from 7 to 9 AM and from 4 to 6 PM.

CALTRANS-11 in Southern California collects travel time data during the peak period. CALTRANS-11 has the capability to collect these data continuously, but normally collects only during the peak period. Trend data are the primary data elements which are recorded daily. Traffic counting is performed by mechanical stations moved from location to location in a continuous traffic count sampling. ADT counts at each location are taken

annually, and all freeway ramps are counted every two years. Annual ADT values present a statewide picture of traffic flow and allow for the evaluation of traffic trends, accident rates, and for planning and designing freeways (41).

The Southwest Washington Regional Transportation Council has identified four elements of the system monitoring program. These elements are: 1) collecting the required data, 2) monitoring the existing or baseline system, 3) preparing future year travel forecasts, and 4) conducting future year evaluations. Data collection must include data for both the congestion measure and the transit/TDM priority. Roadway and traffic data will be collected for each segment during the PM peak period on an annual basis, but only data from the one-hour PM peak are to be used for evaluation. This PM peak period is determined on a location specific basis, rather than for a system wide-peak period. Data are to be collected in both directions at all monitoring locations. The required data includes PM peak-hour traffic volumes, capacities, number of lanes, length of segment, transit service capacity, transit ridership, and average vehicle occupancy (24).

The Bi-State Regional Commission (Illinois and Iowa) does not have a program for monitoring freeway congestion. However, the Iowa and Illinois DOTs make numerous traffic counts on freeways and other highways in the surrounding counties. The Bi-State Regional Commission uses these data to prepare 24-hour non-directional traffic maps, but no use is made of this information to assess traffic congestion at this time.

The St. Cloud APO conducts 48-hour counts using mechanical counters (road tubes) to supplement the counts made by the Minnesota Department of Transportation (MN DOT). The APO conducts their count program May through October. MN DOT makes traffic counts on the state trunk highway system every two years and four years within cities. Two permanent ATR stations are maintained by MN DOT in the St. Cloud APO area.

The Illinois Department of Transportation monitors freeway congestion for the Chicago Area Transportation Study (CATS) using loop detectors spaced at half mile intervals and a traffic surveillance system. The detectors collect loop occupancy data 24 hours a day in five minute intervals for use in computing their measure of congestion (minute-kilometers (minute-miles) of delay, as described in Chapter 2 and Appendix B). Data have been collected using this methodology for many years and provides for a detailed analysis of congestion trends in the Chicago area (14).

The North Carolina DOT does not currently have a program for monitoring freeway congestion. However, monitoring activities are occasionally conducted in work zones and for air quality related projects. For example, speed studies are conducted in work zones and observed queue buildup is observed before, during, and after construction at some locations.

No other interviewed agencies reported congestion monitoring programs for freeways.

State-of-the-Practice for Arterial Streets

CALTRANS-4 monitors congestion on a continuous basis. The traffic count program consists of 12 continuous count stations and 80 count stations which are operated 4 times per year (for both freeways and arterial streets). In addition, 12-hour classification counts are made at 20 locations each year. All surface street segments are counted directionally for a full week (7 days) in one hour intervals on a 3-year cycle. Turning movement counts are considered special counts and are not taken on a regular basis. The Contra Costa County TA also counts traffic manually once a year at key intersections.

The Alameda County CMA monitors congestion on arterial streets on an annual basis. Travel time data are collected during the study period on a Tuesday, Wednesday, or Thursday afternoon during the peak hours of 4 to 6 p.m. The procedure and reasons for monitoring are identical to those Alameda County CMA discussed for freeways.

The San Joaquin County COG requires all local agencies within the county to monitor arterial congestion at signalized intersections on an annual basis. Annual principal arterial LOS calculations are based on traffic counts taken during the calendar year prior to the annual review. Full week counts or counts on Tuesdays, Wednesdays, and Thursdays are preferred. Counts should be avoided around holidays and in the winter and summer months. Counts taken in the spring are considered more representative of average conditions and are consistent with past monitoring activities. Given roadway segments should be counted in the same month each year to provide some degree of validity and consistency. Annual level of service measurements are required to be submitted to the San Joaquin County COG by July 31 of each year (18).

The Los Angeles County Metropolitan Transportation Authority measures LOS at key intersections, spaced approximately two miles apart, which reflect the primary capacity constraints on these principal arterials. A total of 160 intersections have been identified for monitoring across the county. Monitoring activities will occur on an annual basis in conformance with state law. The list will be reviewed annually by the Los Angeles County MTA, CALTRANS, and local agencies. All counts must be taken on at least two weekdays, except not on Monday, Friday, holidays, or when schools are not in session. In addition, counts must be completed during good weather in areas with no road construction or major traffic accidents. At a minimum, peak period counts must include two time periods from 7 to 9 AM and from 4 to 6 PM (15).

The Riverside County TC has recommended to local agencies that a database of key links and intersections be identified for monitoring traffic. These links will be limited in number to reduce costs, but should also provide an adequate picture of the condition of the CMS network. The County is currently developing a program which will utilize detector data from loop detectors or pavement sensors already in place at many intersections. This program will provide count data and turning movements. Therefore, local agencies in Riverside County should keep these intersections in mind for their monitoring activities (16).

The Chicago Area Transportation Study (CATS) recently began monitoring the Strategic Regional Arterial (SRA) network. A consultant was hired to develop a performance methodology using the speed information, traffic counts, and accident information to begin monitoring route performance. In the 1980's CATS developed a program to obtain operating speeds using the floating car technique along the regional highway system. During the past few years, the methodology has been improved to collect operating speeds along the 392 kilometers (245 miles) of the SRA system currently being studied (31).

The St. Cloud APO uses directional traffic counts from approximately 200 total locations each year on the principal and minor arterial systems. MN DOT and the St. Cloud APO collect the data at an equal number of locations (about 100 each) using 15-minute recording mechanical counters. If a location has more than 4 accidents per year, that location will also be monitored for analysis purposes for specific improvement projects. In addition, turning movement counts (12 to 16 hour count periods) are conducted for signal timing and geometric improvement projects. MN DOT, the city of St. Cloud, and the MPO cooperate in making these counts at 6 to 20 locations each year.

The North Carolina DOT does not currently have a program for monitoring arterial street congestion. However, some monitoring of congestion is occasionally completed for research or air quality projects. For example, delay/stop time data have been collected as part of research projects and a travel time study was performed in conjunction with a street conversion to one-way operation (35).

The Charlotte DOT monitors every signalized intersection within the corporate limits at least once every two years. Each intersection is counted to determine the critical v/c ratio for that intersection to determine the appropriate congestion levels. The city operates about 500 signals in 22 coordinated signal systems.

No other agencies reported any congestion monitoring programs for arterial streets.

Costs of Monitoring Congestion

Only a few agencies had any cost data relative to traffic congestion monitoring, with the exception of Alameda County, CA. The reported cost information is based upon staff estimates rather than upon documented cost data or performance audits. While the information obtained is very limited, it is included here for the potential intersect it may have to others. As limited as it is, it is better than no information at all.

The Alameda County CMA contracts with a private consultant to perform travel time studies to monitor the congestion levels on their network. The second year of the monitoring study cost $17,000 for the entire 370 kilometers (230 miles) on the network (740 directional kilometers, 460 directional miles). This translates to a fixed cost of about $45 per route kilometer ($74 per route mile) or $23 per directional kilometer ($37 per directional mile) .

The CALTRANS-4 monitoring program described previously monitors 800 centerline kilometers (500 centerline miles) of freeway. The estimated costs of this program, summarized per 160 centerline kilometers (100 centerline miles) of freeway, are as follows:

- Driver: 0.8 man-years per 160 freeway kilometers (100 freeway miles)
- Data Reduction: 0.15 man-years per 160 freeway kilometers (100 freeway miles)
- Supervision: 0.05 man-years per 160 freeway kilometers (100 freeway miles)
- Car for data collection: 51,200 vehicle-kilometers (32,000 vehicle-miles) per 160 freeway kilometers (100 freeway miles)

Four vehicles are used for collecting travel time data and are operated about 64,000 kilometers (40,000 miles) per year at an estimated cost of 19 cents per kilometer (30 cents per mile).

The St. Cloud APO (Minnesota) reported that their traffic count program takes one person 10 hours per week for the duration of the May through October count season. This includes setting out and packing up the mechanical counters and all data reduction. Other direct counts consist of 80-95 kilometers (50-60 miles) per week.

The Capital District Transportation Committee (New York) reported a cost of $600 per intersection for manual turning movement counts made during 2-hour peak periods in both the morning and the evening. This includes making the counts, data reduction, and preparation of reports. The data processing is fully automated, with the field data entered directly into a PC for calculations using the HCM software.

The conceptual design report for the San Francisco Bay Area Traffic Operations System places the ten year life cycle cost at $289 million for the system covering 736 centerline kilometers (460 centerline miles) of freeway (32). This amounts to an average of $39,250 per centerline kilometer ($62,800 per centerline mile) per year. The system includes ramp metering, traffic volume stations with automatic detection, closed circuit TV, and freeway service patrols. The benefit cost ratio was calculated to be nearly 7 to 1. While the objective of the system is to improve traffic operations, the system can be used as the traffic monitoring element of a CMS. Once such a system is in place, the annual cost for using it for monitoring as part of a CMS should be very small.

Other agencies interviewed did not have estimated cost information for their monitoring program.

Agency Comments

Many agencies had specific ideas regarding how congestion management activities should be structured, including what they thought would work and what would not. The following comments were made by representatives of the various agencies relative to monitoring congestion during the interview process:

- For evaluating point congestion, corridor congestion, and area wide congestion, the Alameda County CMA uses average running speed data collected on an annual basis. LOS is considered sufficient (but not a good performance measure) to describe congestion on highways, but not to provide a measure of mobility in a large urban area with a mature transit system.

- The Washington Department of Transportation stressed the need to all state and local governments to collect the data that are meaningful to them. The data collection requirements must be flexible enough to allow the adaptation of the monitoring system to fit the goals and objectives of the agency.

- Mr. Harvey of CALTRANS-11 stressed there is a great need to increase the funding of congestion management data collection projects.

- The Chicago Area Transportation Study staff feel very strongly that the definition of monitoring of urban congestion must be done at the local level. Several Regional Councils are established, functioning entities and are logical candidates for this function in the northeast Illinois region.

- The North Carolina DOT stated that congestion on rural roadways presents different problems than in urban areas and has received little attention to date. NC DOT presently identifies congested routes in rural areas through the public hearing process. Some better method of monitoring rural highways needs to be identified. Much of the congestion in rural areas occurs during the weekend.

- The Colorado DOT representative stated that, if CMS is to be used for the allocation of funds for congestion mitigation, the same data collection, congestion criteria, performance measure and performance standards need to be used by all jurisdictions.

- The Charlotte DOT staff feels that the CMS regulations should not require the use of delay as a measurement of congestion for monitoring purposes.

Findings

The ISTEA clearly states that long term monitoring and projection of congestion on the designated CMS network is expected. The monitoring of congestion must be integrated with the other management systems for efficient data collection and processing. Figure H-1 suggests the functional relationship of the management systems.

Four of the basic management systems are interrelated, while the pavement management system and the bridge analysis systems essentially stand alone. The traffic monitoring activity overlaps all the basic management systems. This suggests that to the degree possible, the system definitions for the four interrelated systems should have common boundaries.

The air quality district will often include two or more TMAs or MPOs', or a MPO may include all or part of two or more air quality districts. It is desirable that the boundary of the air quality district coincide with a TMA boundary. However, geographic conditions will preclude common boundaries. The San Francisco Bay Area is an example of an especially complex region for which common boundaries are impractical.

Depending upon the measure of congestion selected and the renewal cycle of the TIP, the frequency of the traffic monitoring activity will vary. For a one year renewal cycle of the TIP, annual monitoring studies will be needed. If a two year renewal cycle is used on the TIP, then traffic monitoring studies on a biannual basis will be sufficient to track the changes in congestion on the designated CMS network.

The cost of monitoring congestion depends upon the measure of congestion selected for use. Travel time related measures typically involve test vehicles driven through the system periodically. Travel time studies on the freeway of a moderate size community would involve the commitment of about $15,000 to $20,000 per year. This includes data collection, processing, analysis and reporting costs. Travel time studies on arterial streets appear to be somewhat less costly. The limited data available suggest that a cost in the range of $300 per kilometer ($500 per mile) should be expected for each data collection period.

Figure H-1. Functional Relationship of the Existing Management Systems
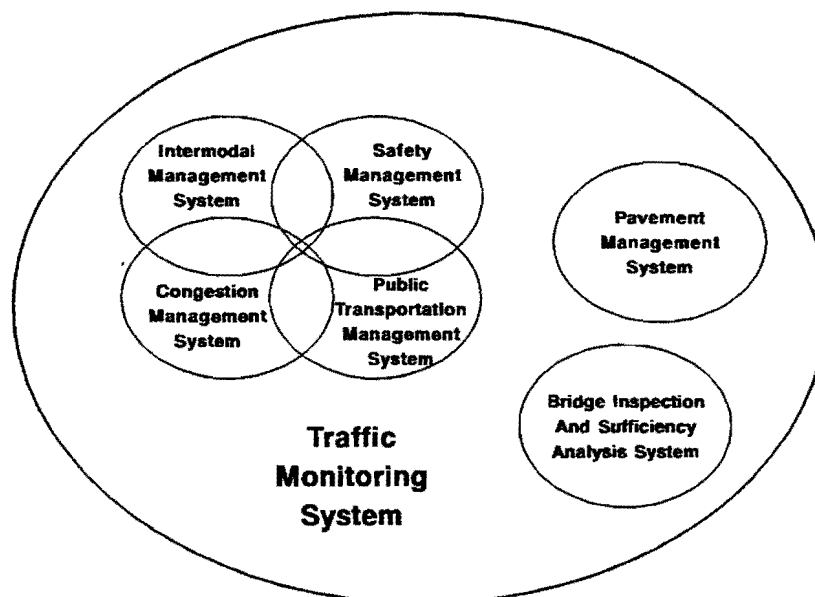
Automated data collection systems reduce the man power necessary to collect the data. However, the initial cost of the automated system is substantial. Typical costs for automated data collection are estimated to be about $74,600 per kilometer ($120,000 per mile) initial cost and $6200 to $7500 per kilometer ($10,000 to $12,000 per mile) annual cost should be expected. This system includes the field hardware at 3.2 kilometer (2 mile) intervals on the arterial system and 8 kilometers (5 miles) on freeways; the control center and the communications network to transmit the data to the control center. This cost structure assumes that freeway ramp control facilities are in place or will come on line with the automated data collection system and bear a large portion of the total cost of the system.

Data to evaluate the level-of-service for an intersection costs $400 to $600. Assuming that data are collected at 1.6 kilometer (1 mile) intervals on arterial streets, the expected cost per kilometer (mile) would be $250 to $375 per kilometer ($400 to $600 per mile) for each data collection period. Volume/capacity ratio analysis requires the same data.

Intersection delay is rarely measured directly in the field due to the difficulty in obtaining the data. Most commonly, intersection delay is calculated based upon counted turn movements and the calculated delay is used to establish the LOS. Delay estimates for roadway segments are normally taken with the travel time data mentioned above.

While many measures of congestion are possible, travel rate (minutes per mile or minutes per kilometer) is probably the most appropriate for a CMS. It applies equally to transit, ferries and auto modes, if one accounts properly for the access times for each mode. As the travel rate increases, the system is becoming more congested. For these reasons travel rate is the recommended measure of congestion. The reader is reminded that monitoring costs are continuous. Any effort in the planning stages that will save money on the data collection will pay off many times in the coming years.

APPENDIX I

STATE-OF-THE-PRACTICE:
USE OF TRANSPORTATION PLANNING MODELS

All references cited with large underlined numbers in this Appendix are identified in the References section beginning on page 29 following Chapter 3.

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Background

Transportation planning agencies have been using computer models for transportation planning since the late 1950's. The various computer programs were originally developed to operate on mainframe computers. Comparable transportation planning program packages for microcomputers such as TRANPLAN, Microtrips, and MINUTP, were subsequently developed and are now widely available at moderate cost. Also, extensive graphics capability have been added to these program packages. Other packages such as EMME II were originally developed for microcomputers. The modeling process was developed for such applications as: 1) the evaluation of different land use-transportation alternatives, 2) evaluation of different land use patterns which might be developed given a transportation system, 3) evaluation of alternative transportation plan to serve a given land use pattern, 4) to identify high volume corridors and to project the approximate travel volumes within these corridors, and 5) to assist in the development of staged improvement programs to implement the adopted plan.

The transportation planning modeling process can be easily used to determine if the land use plan is compatible (coordinated) with the transportation plan. This is done by comparing the modeled future near trip length with the expected mean trip length.

The current modeling process was not designed to evaluate micro-level actions or correlate congestion with air quality. Further refinement of the modeling process is needed to address such issues.

Application of Transportation Planning Models To CMS

A CMS must identify areas where congestion currently occurs. It must also be able to identify areas where congestion may occur in the future. Additionally, the CMS needs to incorporate analytical procedures which can be used to evaluate the potential effectiveness strategies for managing congestion. The transportation planning modeling process can be used to help forecast urban roadway segments which will be congested in the future. The modeling process can also be employed to help evaluate the effect of various factors such as land use management, addition of general purpose lanes, high occupancy vehicle lanes, and combinations of factors which may significantly reduce vehicular travel.

In recent years considerable effort has been devoted to making peak period, or peak hour, assignments with acceptable results. The interest is generated by the fact that unacceptable congestion is in the morning and evening peak period condition and that acceptable levels of congestion exist throughout much of the remainder of the day. Such an assignment requires 1) The coding of a peak period network and 2) development of a peak period trip table. While involving more detail, coding of a peak period network is perhaps conceptually simpler than a 24-hour network. This is due to the fact that there is a relative direct relationship between the operational characteristics of major streets and the links represented in the coded network. However, currently available data are not sufficient

to perform peak hour trip generation directly. Hence, current practice is to function the 24-hour trip tables to obtain a peak period.

Experience has shown that the transportation modeling process provides reasonable forecasts of certain variables which might be used in the forecast of future congestion. These variables include link volumes and average speed. The process can also provide travel rate since travel rate is simply the reciprocal of speed times 60 minutes per hour. Thus, the modeling process can provide the needed information for forecasting such measures of congestion as congestion index (assigned volume divided by acceptable flow rate) and travel rate (minutes per kilometer or per mile).

The current modeling process cannot forecast such variables as queue length, turn volumes, intersection delay or delay by movement, the duration for which average speed will be less than some stated speed, detector occupancy, acceleration noise (the total number of vehicle accelerations and decelerations) and minute-kilometers (minute-miles) of delay. Measures of congestion which depend on such variables are not suitable for use in a CMS.

Link Volumes

Experience shows that the modeling process produces realistic projections of future 24-hour traffic volumes where realistic land use patterns are forecast. Thus, the modeling process can be effectively used to obtain forecast line volumes for use in projecting future congestion using a 24-hour congestion index (i.e. assigning volume divided by "acceptable flow rate"). Where the threshold value is an acceptable hourly flow rate representing acceptable congestion for the specific urban area and type of facility based on traffic control, intersection operations, cross-section, etc. Alternately the assigned 24-hour value might be divided by the peak hour factor and the congestion index calculated using the acceptable hourly flow rate which represents acceptable congestion.

Research by the Texas Transportation Institute (TTI) found that in a large urban area (the Houston-Galveston Transportation Study Region), the peak 60 minutes occurs at different times at different places in the network. These peak hours are shifted by as much as 45 minutes. It was also found that the peak hour (highest value 60 minutes) was a rather constant percentage of the three hour peak period. Consequently this research resulted in the following recommendations for obtaining a peak low assignment.

- Code the network to represent peak hour directional conditions.
- Factor the 24-hour trip tables to obtain a three, or four, hour peak period trip table.
- Assign the peak period trip table to the coded peak hour network.
- Proportion the assigned three, or four hour values to obtain the peak hour directional volume estimates.

Given a peak hour directional assignment, and acceptable peak hour directional flow rates, a peak hour congestion index can be computed to represent potential future conditions.

Due to the complexities of peak period/peak hour modeling it is suggested, that if this practice is used, it be limited to urban areas which have a large sophisticated modeling staff and there are results other than just CMS to prepare per hour directional assignments.

When using the urban transportation modeling process for obtaining forecasts of travel rate or volumes to be used in developing projections of future potential congestion, a multiple path assignment process should be employed. This will provide much more reasonable assigned volumes when travelers have a choice of two or more routes. An all-or-nothing assignment should not be employed.

The volume-capacity restrained assignment process provides a useful tool for identifying locations where traffic is shifted from one corridor to another or from one route to another within the same corridor. This evidence is provided by studying the assigned volumes and/or speeds of successive iterations.

Figure I-1 illustrates a case where the minimum path changes from one route to another and then back again on successive iterations of a volume/capacity restrained assignment. In this case the initial assignment resulted in a high volume, and hence a V/C ratio greater than one. Consequently, on the next assignment the speed was decreased (link travel times were increased and some minimum paths were shifted from this route to an alternate route). The assigned volume on the second iteration was much smaller and the V/C ratio was much less than 1.0. Thus, the link speeds for the third iteration were increased and many minimum paths were high again via this route. And a high volume and a V/C greater than one resulted again. This situation can exist where there are two or more

Figure I-1. Example of Occelation in Assigned Volumes Where Traffic is Shifted from One Corridor to Another in a Capacity Restraint Assignment
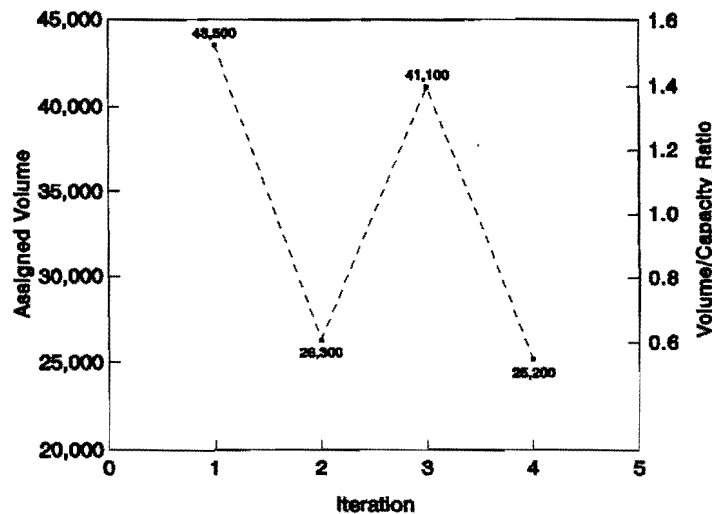
Average of 3 iterations = 36,833 say 36,800
Average of 4 iterations = 33,925 say 33,900

routes (or two or more corridors) serving a number of centroid pairs which interchange a large volume of trips. For the example shown in Figure I-1, using three iterations would result in an assigned volume which is about 10% higher than using four iterations. Use of an even number of iterations (4, 6, etc.) is therefore recommended when using capacity restrained procedures as this will eliminate the use of say two high values and one low value. This use of an even number of iterations should be employed with Equilibrium Assignment as well as when the analysis specifies the percentages from each iteration to be used.

In most cases, the volume, speed and V/C ratio will stabilize provided that a sufficient number of iterations are used. For example, inspection of Figure I-2 indicates that the oscillation is decreasing. However, the pattern suggests that the assigned volume is stabilizing and that the oscillation would decrease if more iterations were used.

While an individual assignment (iteration) from a volume-capacity restraint assignment should never be used as the forecast, analysis of the various iterations is very useful. It helps in understanding how the network is responding in independent to assignment results. The analysis should include the pattern of the speed, volume changes and/or V/C ratios from iteration to iteration. In complex cases it may be useful to plot the minimum path between zone pairs on successive iterations. When analyzing the successive iterations the following patterns might be observed.

1.   Link speed decreases on each successive iteration, assigned volume remains high, V/C ratios continue to be 1.0 or greater. This indicates that there is very high assigned demand relative to capacity and there are no alternative

Figure I-2. Example Where Occelation in the Assigned Volume Decreases
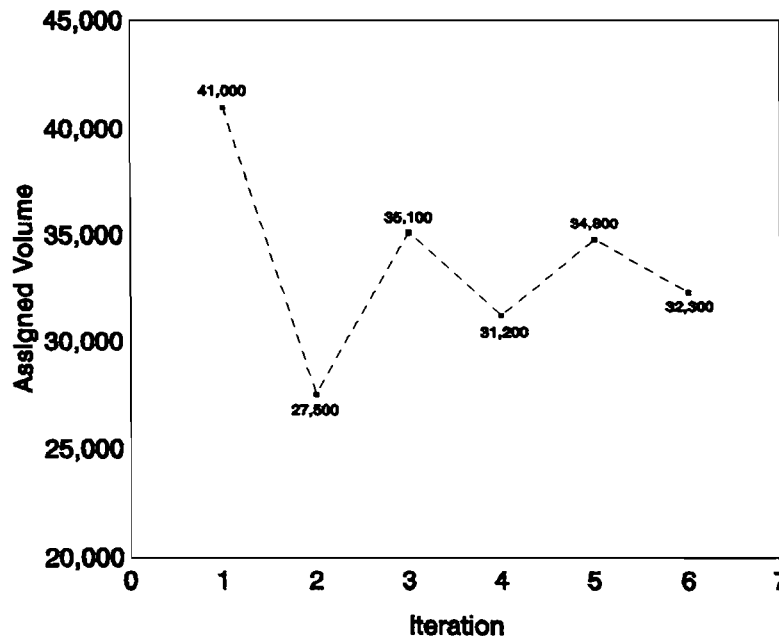
routes/corridors. Several congestions will occur in the future unless a) capacity is greatly increased; b) a different and lower density land development pattern is implemented; or c) some combination of capacity increase and change in the land use pattern is implemented.

2. Link speeds remain high (or increase if the adjustment function permits), assigned volume remains low and increases very little, V/C ratios continue to be much less than 1.0. This indicates that demand is low relative to capacity and no trips are likely to be shifted to this route/corridor from another route or corridor. The route will not experience congestion.

3. The link speed, assigned volumes, and V/C ratios "oscillate" from low to high to low to high (or vice versa) on successive iterations. (For example on the 1st iteration, a high coded speed results in a high volume; on the 2nd iteration, the V/C ratio is again greater than 1.0, speed is decreased and volume decreases; on the 3rd iteration speed is increased, volume increases and the V/C is again close to or greater than 1.0)

This oscillation pattern indicates that there are two or more routes/corridors serving the same origin and destinations and the capacity restraint assignment process is shifting trips back and forth between them. In the real world, drivers will tend to make choices between the alternative routes and the traffic will tend to "balance out."

Turn Movement Volumes

It is generally recognized that the assigned movements from the traffic assignment process must be verified in order to obtain volumes for use in planning and engineering applications. National Cooperative Highway Research Program Report 255 gives a variety of validation and evaluation procedures which should be followed whenever detailed use is to be made of traffic assignment results (36).

It is also generally recognized that assigned left-turn and right-turn volumes are very variable, and in many cases unrealistic. Moreover, the inability to precisely forecast specific development makes it next to impossible to develop even short range turn movement forecasts. For example, Stover (44) has shown that the positioning of a one-million square foot (100,000 square meter) shopping center at different quadrants of the intersection of two major arterials will result in a 100% difference in the projected left-turn and right-turn volumes. Although there are very few comparisons of forecast and actual turn movements and average vehicles intersection delay, experience suggests that the forecasts and actual movements resulting from specific development differ considerably.

A recent paper by Janis Piper (45, pp 47-63) provides a good review of the literature and a summary of the state of the practice including telephone interviews with and review of materials provided by ten state DOT's and one city. It shows that the current practice is very diverse. Most of the practices used to refine the traffic assignment output rely heavily on professional judgment.

The paper by Piper also includes an analysis of observed turning proportions at four-way intersecting streets. The proportions appear to be related to the functional classifications of the intersecting streets. However, the relationship is too variable for use in calculation of the average delay per vehicle using the signalized intersection analysis procedure contained in the Highway Capacity Manual (HCM). Thus, it is concluded that the necessary data to apply the intersection LOS procedure of HCM cannot be forecast with current techniques.

The CMS Network and the Modeling Network

The coded network used in the urban transportation delay process might serve as the basis for selecting the CMS network as has been proposed by various MPOs. Logically it may be assumed that the network used in the modeling process will be more detailed than the CMS network for the two following related reasons. 1) The modeling network will commonly contain many minor links which are included in the coded network in order to obtain a realistic loading of assigned trips to the major roadways represented in the network. 2) Monitoring and forecasting of congestion is relevant to the most important roadways (freeways and principal arterials).

Conclusion

The Urban transportation planning modeling process currently used by urban areas provides an effective method for forecasting where congestion can be expected on major urban roadways. The coded networks traditionally in use are of adequate, or greater, detail than is necessary to provide reasonable results. The output of the modelling process provides information which is suitable for developing travel rates and congestion indices as a measure of future congestion.

Speed and Travel Time

Studies by the Texas Transportation Institute as part of the Houston-Galveston Regional Transportation studies have shown that the modeled travel times compare favorably with actual travel times (46, 47, 48). Since the speeds on the existing network can be reproduced with acceptable accuracy, it should be possible to obtain acceptable forecasts of future speeds on a future network as well. Also, it should be possible to obtain acceptable forecasts of travel time as well since it is a function of the reciprocal of speed and the link length. The following is a summary of the model and its performance.

The Houston-Galveston speed models are based on speed estimation procedures described in a report entitled "Highway Vehicle Speed Estimation Procedures For Use In Emissions Inventories" which was prepared by Cambridge Systematic for EPA in September 1991.

The speed estimation models rely on the speed estimation techniques described in the Highway Capacity Manual (7) (HCM) and are used to estimate the speeds for estimated

volume-to-capacity ratios from zero to one. The extensions of the models for volume-to-capacity ratios exceeding 1.00 are based on the traditional BRP impedance adjustment function, and rely on the assigned volume-to-capacity *(V/C)* ratio as a key measure for estimating the congested speed based on a link's capacity restrained volume. Separate procedures are used for freeways and arterial streets.

The freeway model basically focuses on the decay in speed from a freeflow speed to a Level-of-service E (LOS E) speed as the level of congestion on the link increases from a zero-volume condition to a *V/C* ratio of 1.00. Figure 3-4 of the HCM (7) is used to describe the decay in speeds from a freeflow speed to a Level-of-service E (LOS E). The freeway Subcommittee of the Highway Capacity and Quality of Service Committee of the Transportation Research Board are working on an update and revision of Chapter 3 of HCM (4). One of the revisions is the figure used to develop the speed reduction factors (i.e., Figure 3-3 of the June 20, 1992 draft of the revised Chapter 3 for the HCM (4)). Table I-1 lists the updated speed reduction factors implemented in the Houston-Galveston model; SRF values for intermediate V/C ratios are obtained by interpolation.

Table I-1. Freeway Speed Reduction Factors
Used in the Houston-Galveston Speed Model

V/C Ratio	Speed Reduction Factor (SRF)
0.0	0.0000
0.1	0.0001
0.2	0.0004
0.3	0.0015
0.4	0.0035
0.5	0.0061
0.6	0.0086
0.7	0.0100
0.8	0.1250
0.9	0.4200
1.0	1.0000

After obtaining the speed reduction factor for a freeway link based on its *V/C* ratio from the capacity restrained assignment results, the link's congested speed is computed as follows:

$$S_P = S_{FF} - SRF * (S_{FF} - S_E)$$

where S_P =   Predicted speed for the link,

            S_{FF} =   The free-flow (or zero-volume) speed of the link,

S_E =   The LOS E speed of the link, and
SRF   =   The speed reduction factor corresponding to the link's v/c ratio.

The equilibrium assignment procedure is used to assign the directional link volume for the subject time period (e.g., a 1-hour, 2-hour peak period). The capacities used on the equilibrium assignment model application represent Level-of-service E (LOS E) capacities and can therefore be used directly in computing the link's v/c ratio for application of the freeway speed model.

The arterial and collector street model uses the speed estimation procedures described in Chapters 9 and 11 of the HCM. The model essentially computes average delay per vehicle that would be encountered at a signalized intersection at the level of congestion being experienced (as reflected in the v/c ratio for a link). This delay estimate along with signal spacing information, and the link's freeflow speed estimate is used to compute the average congested speed for a link. The following describes the model formulation in more detail.

At the heart of the model is the estimation of intersection delay. The intersection approach delay for random arrivals is computed using equation 11-2 of the HCM:

$$D = 1.3d$$

where   d   =   average stopped delay (seconds/vehicle) for random arrivals, and
         D   =   intersection approach delay (seconds/vehicle).

The intersection stopped delay equation for random arrivals (i.e., equations 9-18 and 11-3 of the HCM):

$$d = 0.38\frac{[1-g/C]^2}{[1-(g/C)9X)]} + 1.73X^2 \left[(X-1) + \sqrt{(X-1)^2 + \frac{16X}{c}} \right]$$

where   d   =   average stopped delay (seconds/vehicle) for random arrivals,
         C   =   cycle length (seconds),
         g/C   =   the ratio of the effective green time to cycle length,
         X   =   the volume to capacity ratio, and
         c   =   lane capacity (vphpl).

The progression factor, PF, must be applied to yield the stopped delay.

An equilibrium assignment is used to find the directional link volume estimates for the subject time period (e.g.,a 1-hour, 2-hour or 3-hour peak period). The capacities used in the equilibrium assignment model application represent Level-of-service E (LOS E) capacities and can therefore be used directly in computing the link's V/C ratio for application of the arterial and collector speed model.

After computing a link's intersection delay, the congested speed of the link is computed using equation 2-4 of the report entitled "Highway Vehicle Speed Estimation Procedures For Use In Emissions Inventories" (7):

$$S_P = \frac{L}{RTF*[\frac{L}{S_{FF}}] + [\frac{D_S}{3600}]}$$

where

S_p = average running speed for the section (km/h or mph),
L = Length of the section (kilometers or miles),
D_s = Average intersections delay in section (seconds),
RTF= Running Time Factor, and
S_{FF}= Freeflow (zero speed) of the section (km/h or mph).

The running time factors (RTF) vary by freeflow speed and segment length. The running time factors used in the Houston-Galveston model were estimated using the segment running time data from Table 11-4 of the *Highway Capacity Manual* (7). They are simply the ratio of the segment running time per kilometer (mile) divided by the freeflow speed travel time per kilometer (mile).

The delay estimation procedures work well for *v/c* ratios up to 1.0. With regard to the delay equation, the *HCM* cautions that: " The equation may be used with caution for X up to 1.2". In the Houston-Galveston applications, the arterial and collector street model is used for *V/C* ratios greater than 1.0. Since assigned volumes can greatly exceed the limits a procedure is used to extend the HCM relationships for higher *V/C* ratios over 1.00. The current (1993) Houston model extensions are:

- For freeways and expressways with a *V/C* ratio over 1.0:

$$S_P = S_{PI} * \frac{1.15}{1.0 + 0.15*(\frac{V}{C})^4}$$

where

S_p = Predicted speed for the link,
S_{pI} = The speed on the link for a *V/C* ratio of 1.0, and
V/C = the estimated flow rate *V/C* ratio for the link.

- For arterials and collectors with a *V/C* ratio over 1.0:

$$S_P = S_{PI} * \frac{1.15}{1.0 + 0.15*(\frac{V}{C})^2}$$

These models provide the extension needed for HCM relationships implemented in the freeway model and the arterial and collector model.

Local Street Speed Estimates

Since centroid connectors generally represent multiple local streets and operate under uncongested conditions, the centroid connectors are not assigned a capacity. Since local streets generally operate under relatively uncongested conditions, the 4-hour centroid connector speeds are used for the various time-of-day assignments.

The results of the H-GAC's 1985 assignments were compared with the Texas Department of Transportation's 1985 observed travel time/speed data. This extensive 1985 data base included observed directional two-hour peak period travel-times and speeds on more than 2,000 links with morning and afternoon directional speeds (i.e. four observed speeds: a morning peak speed in the peak direction, a morning peak speed in the off-peak direction, an afternoon peak speed in the peak direction, and an afternoon peak speed in the off-peak direction). In effect, the two networks contain more than 8,000 observed link speeds.

This analysis indicates that the transportation modeling process can produce reliable speed and, hence, travel time results. Thus, the modeling process might be used to forecast future peak hour travel rate (minutes per kilometer or mile). The current state of traffic assignment practice, however, does not produce speed and duration information (i.e. the length of time during a peak period that speed is less than some selected value such as less than 55 km/h (35 mph)).

Since the modeling process can reproduce existing speeds with acceptable accuracy, it is reasonable to expect that it can also produce useful forecasts of future network speeds. This being the case, it is a simple matter to obtain forecasts of future travel rates since travel rate is the reciprocal of speed. Table I-2 gives the corresponding travel rate for various speeds.

State-Level Forecasts and Trend Analysis

The procedure for forecasting future traffic volumes on state highway systems outside of urban areas rely heavily on the historical trends. Very few states have developed statewide computerized, network based models comparable to those used in urban transportation planning studies.

Trend analysis relies on counted volumes which were made at the same locations over a period of years. The procedures commonly used are manual calculations which are made separately for each location of interest for which historical count data are available. Two common procedures are: 1) extrapolation and 2) growth factor. They differ only in the way the historical count data are utilized.

Table I-2. Travel Rate Corresponding to Various Speeds

Speed km/h (mph)	8 (5)	16 (10)	24 (15)	32 (20)	40 (25)	48 (30)	56 (35)	64 (40)	72 (45)
Travel Rate minutes per kilometer (mile)	7.5 (12)	3.7 (6)	2.5 (4)	1.9 (3)	1.5 (2.4)	1.24 (2.0)	1.06 (1.7)	0.93 (1.5)	0.83 (1.3)
Speed, km/h (mph)	80 (50)	88 (55)	96 (60)	105 (65)	113 (70)	120 (75)	129 (80)	137 (85)	145 (90)
Travel Rate minutes per kilometer (mile)	0.75 (1.2)	0.68 (1.1)	0.62 (1.0)	0.57 (0.9)	0.53 (0.9)	0.50 (0.8)	0.47 (0.8)	0.44 (0.7)	0.42 (0.7)

Both procedures are applicable to situations where the growth is expected to continue in the future as it has in the past. However, extrapolation and growth factor methods for statewide activity patterns are constantly changing. (i.e. where several urban areas are growing at different rates and/or where business and industrial development location patterns are in a state of change.)

The Texas DOT uses an annual growth rate model to forecast future traffic volumes. Simple linear regression is used to determine the regression coefficients b_o and b_1 in the following generic simple regression equation:

$$Y = b_o + b_1 X$$

where

Y	=	the dependent variable, ADT(t) which is the average daily traffic in vehicles per day (vpd) expanded from short course data;
b_o	=	the regression constant, ADT(0) which is in vpd;
b_1	=	the regression coefficient, G which is ADT growth in vpd; and
X	=	the independent variable time measured in years, t.

Replacement of the generic variables with the specific variables result in the following equation.

Table I-3. Comparison of the Modeled and Observed
for the 1985 AM and PM Two-Hour Peak Period Assignments

Area Type	Row Contents	Freeway Links	Arterial & Collector Links	Combined
CBD & Urban	# observed link speeds			
	Average modeled speed	684	1502	2186
	Average observed speed	43.3	25.9	39.3
	Average difference	44.6	25.8	40.3
	Average percent	-1.4	0.1	-1.0
	difference	-3.1%	0.3%	-2.6%
Inner Suburban	# observed link speeds			
	Average modeled speed	598	2235	2833
	Average observed speed	42.0	27.3	36.1
	Average difference	40.5	27.3	35.2
	Average percent	1.5	0.0	0.8
	difference	3.8%	0.2%	2.3%
Fringe Suburban	# observed link speeds			
	Average modeled speed	384	772	2091
	Average observed speed	53.6	52.2	42.6
	Average difference	56.8	51.3	42.9
	Average percent	-3.2	0.9	-0.3
	difference	-5.6%	1.8%	-0.6%
Rural	# observed link speeds			
	Average modeled speed	212	772	984
	Average observed speed	61.0	52.2	56.2
	Average difference	60.5	51.3	55.4
	Average percent	0.5	0.9	0.7
	difference	0.8%	1.8%	1.3%
All	# observed link speeds			
	Average modeled speed	1868	6226	8094
	Average observed speed	44.9	31.6	39.6
	Average difference	45.0	31.3	39.5
	Average percent	-0.1	0.3	0.1
	difference	-0.2%	1.1%	0.3%

$$ADT(t) = ADT(0) + Gt$$

The average annual ADT growth rate is found by dividing G by ADT(0).

$$GR = G \div ADT(0)$$

The model for projecting future traffic volume is then:

$$ADT_{future} = ADT_{current} * [(1 + GR_{adt}) ** (T)]$$

where

ADT_{future}	=	the projected ADT in N years,
$ADT_{current}$	=	the current year ADT,
GR_{adt}	=	the annual growth rate as a fraction, and
T	=	the number of years from the current year to the forecast year.

A recent study by the Texas Transportation Institute (TTI) found that the TxDOT model provided good results when compared to the actual traffic growth for a 16-year period of the majority of 56 ATR station (47). The research also reported that the model performed favorably when compared to more complex models.

Statewide Models

In the late 1960's and early 1970's there was substantial optimism that the urban travel demand modeling procedures (used in estimating and forecasting urban highway volumes on major facilities) could also be adapted and used to forecast intercity highway travel. However, few such statewide models were ever implemented. Michigan and Kentucky are the two most commonly cited statewide network-based modeling procedures directed toward forecasting intercity highway volumes.

In recent years, substantial interest and efforts have been directed toward more macroscopic intercity modeling efforts which focus on modal choice issues (i.e., air versus rail versus highway) for intercity travel between major destinations. While these multimodal modeling systems have a highway component, they are not directed toward forecasting highway volumes on a detailed highway network such as a state CMS network. The Florida statewide multi-modal travel models are a good example of this type of statewide modeling system. In the Florida models, the entire United States is included in their zone structure. Florida's 67 counties are treated as individual zones. Groups of counties in Alabama and Georgia along the Florida border are aggregated into zones. The remainder of Alabama and Georgia, the other 47 states, and the District of Columbia are designated as zones. This level of detail is certainly appropriate for multi-modal analyses which focus primarily on longer intercity trips having mode-choice options.

In contrast to the Florida system which uses 67 in-state zones, the Kentucky models use 663 in-state zones. The Michigan DOT reported that they are developing a 2,300-zone system for use in some of their highway analyses.

Michigan

The Michigan Statewide Highway Network Model is a modeling system which uses a basic three-step modeling process: trip generation, trip distribution, and traffic assignment. The modeling process is directed toward estimation of intercity highway volumes on the major highway facilities in the state.

The in-state zones generally consist of an aggregation of one or more contiguous townships and/or cities. All cities with a population exceeding 10,000, with the exception of Detroit, are designated as a zone (Detroit is split into three zones). The highway facilities represented in the statewide network include all interstate, U.S., and Michigan (state) routes as well as "significant" county roads. In the 1975 model update, 508 in-state zones and 39 out-of-state zones were used.

The Michigan models generate, distribute, and assign only interzonal vehicle trips. Three trip purposes are used: general intercity trips, heavy truck intercity trips, and vacation intercity trips.

The trip generation models for the general intercity trips and the heavy truck intercity trips are used to estimate trip origins and destinations by zone (rather than trip productions and attractions by zone.)

The Michigan trip generation models recognize that the number of interzonal trips generated for a zone is not only a function of the activity within a zone but also a function of activity in the nearby zones. They basically use two independent variables: (1) the population within the zone, and (2) an external population variable computed time include 100 percent of the external population of zones within 20 minutes of the zone plus 50 percent of the population of zone within 20 to 30 minutes of the zone plus 25 percent of the population of zones within 30 to 40 minutes of the zone. These models were developed using origin-destination (O-D) external cordon survey data from ten cities in Michigan.

The trip distribution for both the general intercity trips and the heavy truck intercity trips are performed using a gravity model. The "deterrence function" (i.e., essentially the gravity model F-factors) was developed using the observed trip length frequency data from the ten urban external cordon O-D surveys.

The estimation of Vacation Intercity trips relied on data from four sources: a tourist survey conducted for the state, the Mackinac Bridge Study, Highway Department Statistics and the ten urban external cordon O-D surveys. Three categories of Vacation Intercity trips are used: Michigan residents vacationing within the state, Michigan residents vacationing out of state, and Out-of-state residents vacationing in Michigan. Trip generation estimates

for these three categories are initially estimated at the state level (not the zonal level) and are used as control totals.

The trip generation process for two of the categories (i.e., the Michigan residents vacationing within the state and the out-of-state residents vacationing within Michigan) might be described as a "top-down allocation process." The vacation attractions within the state for each category (i.e., the vacation destinations) are allocated from the state level to the zonal level based on indices developed using the tourist survey. The productions by category are allocated from the state level to the zonal level based on population indices.

The trip distributions for two of the categories (i.e., the Michigan residents vacationing within the state and the out-of-state residents vacationing within Michigan) are performed using a gravity model. These gravity model applications are somewhat unique in that the scaling is performed relative to attractions rather than the more conventional production-to-attraction approach. The Mackinac Bridge Study data were used as a means for establishing a "relative deterrence function."

For the third category of vacation trips (i.e., the Michigan residents destined to out-of-state vacation attractions), the statewide control total is allocated directly to the zonal interchange level based on the product of the zonal populations. In effect, no deterrence function due to spatial separation is employed in the distribution process.

The final step in the modeling chain is traffic assignment. The resulting five trip tables are combined to obtain the trip table for assignment.

The initial 1965 base year assignment results were compared with counted volumes on 30 links with permanent count stations. These comparisons indicated an average over-assignment of approximately 57 percent (or an average absolute error of approximately 76 percent). To correct for this bias, the assignment results were simply scaled by a factor of 0.64. The use of the scaling factor resulted in an average absolute percent error of approximately 40 percent for the 30 links. Before applying the 0.64 scaling factor, only six of the 30 links had assigned volumes within ± 25 percent of the counted volumes; 13 of the 30 were within ± 50 percent and 22 of the 30 were within ± 100 percent. Eight of the 30 links had unscaled assignment volumes which exceeded the counted volume by more than 100 percent. After applying the 0.64 scale factor, 10 of the 30 links had assigned volumes within ± 25 percent of the counted volumes, 22 of the 30 were within ± 50 percent and 20 of the 30 were within ± 100 percent.

In the late 1970's, the Michigan Statewide Models were updated to a new base year of 1975. One of the main objectives of this update was to recalibrate the models so that a majority of the assigned link volumes would be within ± 10 percent of the counted ADT. To achieve this objective, the trip generation and distribution models had to be adjusted on an area-specific or zone-specific basis to better reflect the observed travel patterns.

The updated Michigan models were subsequently applied to forecast the year 2000 intercity highway volumes. These forecasted volumes were graphically compared to observed trends from 1966 through 1977 at 32 permanent count stations located throughout the state. This graphical comparison indicated that the model was producing forecasted volumes that were very consistent with observed trends. Based on these comparisons and the calibration results, the Michigan report concludes:

> ...If the assumptions and limitations are clearly understood, the model can be used for future year forecasts. Additionally, general consensus by users of the model to date have, for the most part, found future year forecasts reasonable relative to other forecasts derived by manual forecasting methods (43).

Kentucky

The Kentucky Statewide Traffic Model (developed in the 1970's) is a modeling system that uses a basic three-step modeling process: trip generation, trip distribution, and traffic assignment. The modeling process is directed toward estimating average daily volumes on major intercity highway facilities.

The Kentucky model's zone structure uses 663 in-state zones and 118 out-of-state zones. The 663 in-state zones were formed to correspond to the census county division and aggregation of traffic analysis units in urban and rural areas, respectively. Major recreation areas within the state are treated as independent zones. The 118 out-of-state zones are used to represent the remainder of the continental U.S., Canada, and Mexico. The 118 zones were developed by taking a single county or combination of two or more counties in the adjacent states and single state or combination of states for the remainder of the nation. Canada and Mexico are each represented by a single zone.

The in-state network contains about 17,600 kilometers (11,000 miles) of highway system (represented using 6,000 links). The highway network includes essentially all of the Interstate facilities, toll roads, and the state primary facilities. The network also includes about 70 percent of the state secondary facilities and about 11 percent of the rural secondary facilities.

One of the major differences between the Michigan and Kentucky models is that the Kentucky models generate and distribute all vehicle trips (not just the interzonal or intercity vehicle trips). Three types of surveys were conducted for use in developing the Kentucky models:

(1)   Household Travel Survey: The household travel survey was conducted by mailing questionnaires to a sample of the in-state auto-owning households. The nominal sampling rate use in the sample selection was approximately 1.5 percent with a minimum sample size requirement of 60 households in each county (i.e., a sample size of 14,979 households). The useable responses rate was approximately 45 percent (i.e., 6,713 total useable responses).

(2)   Roadside O-D Surveys: roadside O-D surveys were conducted on the cordon line and at certain internal locations.

(3)   Truck Travel Survey: The truck travel survey was conducted along with the FHWA-sponsored National Truck Commodity Flow Survey by sending questionnaires to a 2 percent sample of truck registrants.

The Kentucky Models use three trip purposes: "short" vehicle trips (i.e., trips less than or equal to 35 minutes); "long" vehicle trips (i.e., trips over 35 minutes); and, truck trips. A cross-classification of households by population density and auto ownership is used to estimate total zonal productions. The trip rate corresponding to the auto ownership level and population density strata designation is used with household data to compute total trips produced in each zone. Trips are then split into long and short trips based on trip length. Following a county-level comparison of observed and assigned VKT (VMT) in which the modeled or assigned VKT (VMT) was found to be greater than the observed VKT (VMT), the trip rates were "adjusted" on a county basis. Therefore, trip rates vary not only by zonal population and auto ownership but also by trip length as well as by county throughout the state. Trip attractions are calculated for short trips based on "analysis units" which are aggregations of zones. Due to the unique manner in which the distribution of long trips is performed, it was not necessary to estimate attractions for long trips.

Short trips were separated into intrastate and interstate trips for purposes of trip distribution. Distribution of intrastate short trips was performed with a gravity model with a set of F-factors calibrated using the household travel survey. Base year modeling of short interstate trips was accomplished by expanding an external cordon survey trip table. For future year traffic, a FRATAR technique was used to growth-factor this short interstate trip table.

The developers of the Kentucky model did not feel that a gravity model was suitable technique to be used in the distribution of long trips. A new and unique trip distribution process referred to as "Long Trip Distribution Model" was developed to carry out the distribution of long trips. According to the model's developers, the model is based on the theory that:

> ...trip interchanges between a set of two areas of given populations sizes and spatial separation will demonstrate a stable "production/attraction" ratio which is characteristic of all sets of areas with the same population sizes and spatial separation characteristics (43).

The expanded statewide travel survey trip table was used to develop these ratios for the long trips.

In the early stages of the development of the Kentucky model, truck trips were not directly modeled. Instead, the assigned volumes from the other two trip purposes were simply factored to estimate truck trips. Later, it was found that the use of a "calibrated"

truck trip table yielded better assignment results. However, the available documentation does not describe the process used to develop the calibrated trip table.

The assignment of trips to the Kentucky Statewide network was performed using a simple all-or-nothing minimum travel time path procedure. Observed speeds are used in the calculation of the minimum time paths.

Observations

The Michigan and Kentucky statewide models are essentially an adaptation of the three-step urban travel demand models (i.e., vehicle trip generation, trip distribution, and traffic assignment). Comparison of these models to their urban counterparts reveals some key differences which highlight some of the fundamental problems in adapting the urban travel modeling techniques for statewide applications.

The level of detail used in the zone structure is perhaps the most obvious difference between urban areas and statewide modeling.

In urban travel models employing a large number of relative small zones, the portion of vehicle trips which are intrazonal trips (i.e., trips with both the trip origin and trip destination within the zone) is normally very small. For example, in the 8-county Houston-Galveston regional transportation models which has 2,600 zones, less than 5 percent of the total trips are estimated to be intrazonal trips.

Since statewide models typically use much larger zones, it is not unusual for a small city or town to be represented by a single zone. In such instances, a very large majority of the daily vehicle trips would be intrazonal trips. Since only interzonal trips are assigned to the network, one of the key factors influencing the success of a statewide model is, in effect, its ability to accurately estimate the number of interzonal trips for each zone. Indeed, the portion of the trips that would be intrazonal trips is, at least in part and perhaps largely, a function of the intrazonal versus interzonal travel opportunities (For example, a small city or town which is represented as a single zone). In such instances, a very large majority of the daily vehicle trips would be intrazonal trips.

In the Michigan statewide model, this problem is taken on in a very direct manner. The Michigan trip generation models directly generate only interzonal trips.

These two desirable characteristics could be restated in terms of total trips, interzonal trips, and intrazonal trips as follows.

1.   As a zone's population increases, the total trips generated in the zone will increase. Also, as the zone's population increases and the external environment for the zone remains unchanged, both the percent of intrazonal trips will increase and the number of interzonal trips will increase. Hence, the number of interzonal trips will increase less rapidly than the population.

2.   As the external population near a zone increases and the zone's population remains constant, the percent of intrazonal trips will decrease and the number of interzonal trips will increase.

Typically, in urban transportation studies, the application of the trip distribution model will reflect these two characteristics. To some extent, the Michigan trip generation model's weighing of the external population by time periods might be considered a coarse way of reflecting the impedance to travel due to spatial separation (which is represented in the gravity model analogy by F-factor).

In contrast, the Kentucky Statewide Models actually generate total trip productions which are split into two groups: Short trips (i.e., trip length of 35 minutes or less) and long trips (depending on the zone's population density strata and stratification of households by auto ownership). Short trip attractions are also generated based on the zone's population and employment estimates. The gravity model is then applied to distribute the short trips. The long trips (i.e., the trips over 35 minutes) are distributed using a special trip distribution model developed specifically for the Kentucky applications. In effect, the gravity model application determines what portion of the short trips are intrazonal trips. On the surface, this is very appealing. However, it should be recalled the Kentucky model developers found it was necessary to adjust the short trip production rates for each county based on comparisons of counted versus assigned VKT (VMT). In essence, it was assumed that the differences in the assigned and counted volumes were due to weaknesses in the short trip production rates. It is likely that the problems being observed were not totally trip generation problems but were at least in part a trip distribution problem related to intrazonal trips. For example, if a zone should have retained 85 percent of its trips as intrazonal but the distribution model is producing an estimate of 80 percent intrazonal, then the zone would, in effect, be producing 25 percent too many interzonal trips for assignment. If this were the problem, it can often be corrected in conventional gravity model applications by simply changing the user-supplied intrazonal time estimate by 1 or 2 minutes (thereby changing the gravity model F-factor used in the intrazonal trip estimate). Again, the problem in dealing with the very large zones used in statewide models where a majority of the trips produced should be intrazonal trips is that the assignment can be very sensitive to relatively small variations in the intrazonal trip estimates.

In urban travel modeling, a similar problem is encountered in sketch planning applications which use substantially larger than normal zone sizes. Although sketch planning zones are substantially larger than the normal zone size used in urban studies, they would generally be much smaller than the zones used in statewide model applications. Indeed the problems of reasonably estimating the intrazonal trip in sketch planning applications was one of the problems which lead to the development of atomistic trip distribution model.

In urban transportation studies, the placement of zonal centroids and centroid connectors is generally given substantial attention in the network development to attempt to assure that the trips to and from a zone are loaded on the network properly. By using a large number of relatively small zones, the centroid loading problems are reduced but not

eliminated. With the very large zones used in statewide models, centroid loading problems can create substantial "noise" in the assignment results.

In urban travel modeling, trip length frequency estimates by trip purpose are used either directly in the trip distribution modeling process or indirectly as the criteria for calibrating gravity model F-factors (i.e., factors which reflect the impedance to travel due to spatial separation.) Urban travel survey data generally provide a very good estimate of the average trip length of trips by purpose and a reasonably good estimate of the shape of the trip length frequency distribution. The shape of the trip length frequency distribution for longer trips (e.g., trips over 40 network minutes using 24-hour network speeds) is probably the weakest part of the trip length frequency estimates. However, since the vast majority of the urban trips are short to medium length trips (e.g., trips under 40 network minutes), urban traffic assignment results are generally not very sensitive to the trip length frequency distribution of the longer trips so long as overall trip length frequency distribution provides a good estimate of the average trip length.

Statewide models by their very nature, will be more sensitive to the trip length frequency estimates for the long trips than the urban models. Although this is a more difficult problem to deal with in statewide studies, it is not insurmountable. Indeed, with good urban external cordon survey data from a number of urban areas within the state, there are probably sufficient data to develop a reasonable set of F-factors (friction factors) for use in statewide gravity model applications.

Urban travel models generally require relatively detailed estimates of demographic variables at the zonal level. For example, the Houston-Galveston travel models use zonal household estimates (cross-stratified by five household income groups and five household size groups) and zonal employment estimates (stratified by six employment types). In sharp contrast, the Michigan statewide models essentially use zonal population as their basic demographic data input. The Kentucky statewide models use zonal estimates of car-owning households (stratified by 1 car, 2 car and 3+ car households), zonal population, and zonal employment as their basic demographic data inputs. For statewide modeling, it is desirable to keep the demographic data forecasts on a statewide basis. This is certainly consistent with the more macroscopic nature of statewide modeling. Indeed, with the large zones used in statewide models, there are probably less differences in the trips per household between zones than can be observed for the small zones in urban transportation studies.

The assigned volumes on higher volume facilities (such as freeways and principal arterials) are typically more accurate than the lower volume facilities (such as secondary arterials and major collectors). In urban transportation studies, these lower volume facilities are really not the focus of the analyses and evaluation. Unfortunately, in statewide systems, many lower volume facilities will be of interest. Also, given the more macroscopic level of application of the travel models at the statewide level, it is reasonable to expect that the variance of estimates on lower volume facilities will be greater in statewide studies than in urban studies.

Neither the Kentucky nor the Michigan statewide models are portable in the sense that they could be obtained and applied in other states without major recalibration.

The principal data base for the Michigan models was the external cordon surveys from 10 urban areas. The statewide household travel survey with 6,713 useable responses was the principal data base for the Kentucky models. In both states, it was found that the use of a single set of statewide trip generation models did not produce desirable traffic assignment results. Both required substantial local adjustments to produce acceptable assignment results. With this level of localized adjustments, a simple set of synthesized rates would provide as good a starting point as the values developed using the statewide travel survey. Indeed, based on the experiences of these two states, it would be difficult to recommend an extensive travel survey for use in developing trip generation models.

The Michigan model is judged to be the more desirable of the two approaches for the following reasons.

a. The Michigan model uses population as the basic data. From a statewide modeling perspective, it is certainly desirable to keep the demographic data requirements as simple as possible. The Kentucky model requires zonal estimates of households by auto ownership, population, and employment.

b. The intrazonal problems of statewide modeling are lessened by directly generating interzonal trips based on the zone's population and the population of nearby zones. The Kentucky approach of generating total trips and splitting them into long and short trips based on trip generation variables rather than considering the location of the zone relative to other travel opportunities was judged to be less desirable.

c. A gravity model is used in the Michigan trip distribution.

d. The year 2000 forecasts using the 1975 update of the Michigan model compared very favorably with the observed trends at the 32 permanent count locations.

Comparisons of the Michigan modeled results with observed trends at their 32 permanent count locations indicates that extrapolation of observed traffic growth trends would have produced forecasts which would be very comparable to the Michigan statewide model forecasts.

The primary recommendation is that the Department not undertake development of a statewide travel model. The available data does not indicate that the implementation of statewide models (comparable to the urban transportation models) will improve the quality of the intercity travel forecasts. It is believed that this is due to the difficulties in forecasting trip generations and to a lesser extent, trip distribution.

If it is determined that a detailed set of statewide models is needed, the modeling process might be used to estimate the expected percent increase in traffic on a detailed network rather than to forecast link volumes directly. The expected percent change would be applied to the base year count data to forecast the future year volume. Using this

approach, the Michigan general trip and truck trip models could be adapted for use in estimating the expected percent change.

APPENDIX J

STATE-OF-THE-PRACTICE:
AGENCY ORGANIZATION AND PROJECT IMPLEMENTATION

All references cited in large underlined numbers in this Appendix are identified in the References section beginning on page 29 following Chapter 3.

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Proposed Federal Requirements for Agency Organization and CMS Implementation

The proposed rules for congestion management systems as required by ISTEA were published in the *Federal Register* on March 2, 1993 (3). The proposed rules require each state to develop, establish and implement a CMS on a continuing basis. The rules state that:

> The CMS must cover the entire state, but may consist of sub-systems for each metropolitan and non-metropolitan area. The State may enter into agreements with metropolitan planning organizations (MPOs), local governments, and other appropriate agencies for the development, establishment, and implementation of appropriate portions of the CMS, but the State shall be responsible for ensuring that the CMS is implemented in accordance with the requirements of the regulations in this subpart. (p. 12120, §500.505b)

> The State is directly responsible for all congestion management activities, but in many cases the CMS activities will be carried out by the MPO. States are required to cooperate with the local agencies and with agencies affected by the Federal Transit Act during the development, establishment, and implementation of the CMS. In addition, for air pollution non-attainment areas, the State will be required to coordinate CMS activities with the transportation control measures indicated in the State implementation plan required by the Clean Air Act. (p. 12120, §500.505c,d,e)

> The CMS identified by the State shall identify and evaluate anticipated performance, based on the area's established performance measures, and expected benefits of traditional and nontraditional strategies for efficient use of the transportation system. The strategies suggested for consideration include the following:

> 1. Transportation Demand Management;
> 2. Traffic Operations Improvements;
> 3. Measures to encourage increased HOV use;
> 4. Congestion Pricing;
> 5. Growth Management Strategies;
> 6. Access Management Strategies;
> 7. Incident Management Strategies;
> 8. Applications of IVHS Technology; and
> 9. Addition of General Purpose Lanes.

For each strategy proposed for a CMS project, implementation responsibilities, implementation time frame, and probable funding sources need to be identified as a minimum. In all areas, priority shall be placed on strategies that improve the efficiency of the existing transportation system, specifically by reducing the number of single-occupant vehicles. In the event that the addition of general purpose lanes is determined to be the appropriate strategy, consideration shall be given to future demand and operational

strategies which will serve to maintain the functional integrity of those lanes. The effectiveness of the implemented strategies should be evaluated periodically in terms of the area's established performance measures, and the results need to be available for providing guidance on future project implementation. It should be noted that in air quality nonattainment areas highway or transit projects which significantly increase capacity for single occupant vehicles must result from an approved CMS.

State-of-the-Practice of Agency Organization

In addition to the California counties covered by the State CMS legislation, the Southwest Washington Regional Transportation Council, Pima AOG, Denver Regional COG, Pikes Peak COG, and Colorado DOT have all recently begun comprehensive studies on the development of CMS programs. Initial results provided by their individual consultants have provided several viewpoints regarding agency organization and structure of the CMS.

The Southwest Washington RTC's consultant has recommended a structure based upon the following four guidelines: 1) respond to the minimum requirements set forth in the NPRM, 2) focus on congestion, 3) be practical and easy to apply, and 4) emphasize regional travel characteristics. Additionally, the CMS strategy must be able to address the congestion related issues which are a requirement of the Washington State Growth

Figure J-1. Southwest Washington RTC Proposed CMS Structure
SOURCE: Reference (19), p. 5-4.
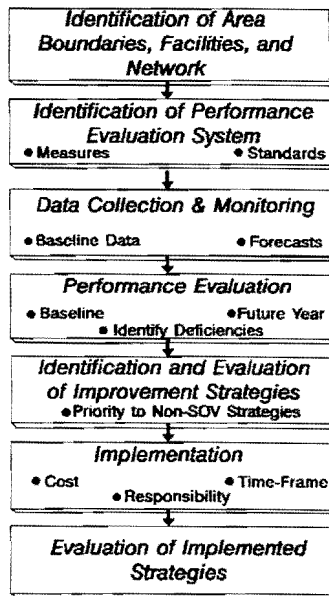
Management Act. The proposed CMS structure for the Vancouver area is shown in Figure J-1. The CMS being developed in Vancouver is a subsystem of the statewide CMS system. However, the Washington DOT has delegated very broad responsibility to the Southwest Washington RTC and the other MPOs which are TMAs. The remaining MPOs are being encouraged to take responsibility for the CMS in their area. The system is simplistic in that it is practical to apply. Once further experience is gained, complexity may be added to the system (19).

Multi-modal issues will be addressed in conjunction with the Public Transportation Management System and the Intermodal Management System. Within the CMS, consideration of transit and TDM strategies as congestion reduction strategies are the primary methods of addressing multi-modal issues. The Southwest Washington RTC is designed from a regional perspective to provide a regional picture of the transportation system rather than focusing on localized details (19).

The Denver Regional COG, Pikes Peak COG, and Colorado DOT joined forces and issued a joint request for proposals (RFP) for the design of congestion management systems for both the State of Colorado and the two TMAs (44). The RFP identified the concerns and topics the agencies thought were necessary in order to fully implement a congestion management system. The resulting contract work is currently underway, with Tasks 1 and 2 completed in draft form and Tasks 3 and 4 underway.

The Pima Association of Governments in Tucson, Arizona retained a consultant to research, develop, and implement their congestion management system. The consultant completed an exhaustive literature review including land use evaluation programs, TDM/TSM strategies, Level of Service evaluation procedures, legislative requirements, and implementing and monitoring the system (4). The technical memoranda prepared for the Pima AOG provide excellent documentation of the various facts concerning the development of a CMS. The interested reader should request copies for their use (52, 53, 54, 55, 56, 57, 58, 59, 60, 61).

In many cases the state highway agency expects to delegate the major responsibility for the CMS to the various MPOs within the state. In others, only those MPOs which are responsible for a TMA will have primary responsibility delegated to them. Arizona DOT reported that the Pima AOG and Maricopa Association of Governments, both of which are TMAs will have the responsibility. AzDOT will prepare the CMS for the remainder of the state, including Yuma which is the only other MPO in Arizona. The Pikes Peak and Denver area COG's will have responsibility for their areas, both of which are TMAs. Colorado DOT will incorporate them into the State CMS; the CMS for the MPO areas will be prepared by Colorado DOT as part of the state CMS.

Washington and Florida DOT's reportedly will encourage the several MPOs in the state to accept primary responsibility for the CMS for each metropolitan area. The DOT will actively participate with each MPO and incorporate them into the state CMS. The

entire state of New Jersey is covered by three MPOs. The NJ DOT will assist each MPO as may be needed and assemble them into the State CMS.

Each urban county in California is required to have a Congestion Management Agency (CMA) by California law. The CMAs were created by voter action in 1990. The California legislation mandates county-wide CMAs in every county with an urbanized population over 50,000 (32 of the 58 Californian counties). The CMAs must develop a Congestion Management Program (CMP), which is required by California law to be updated every two years. After seven years, the CMP must be rewritten. The congestion management program process recommended in the *Congestion Management Program Resource Handbook* (62) developed by a consortium of agencies in California is shown in

Figure J-2. California Congestion Management Program Process
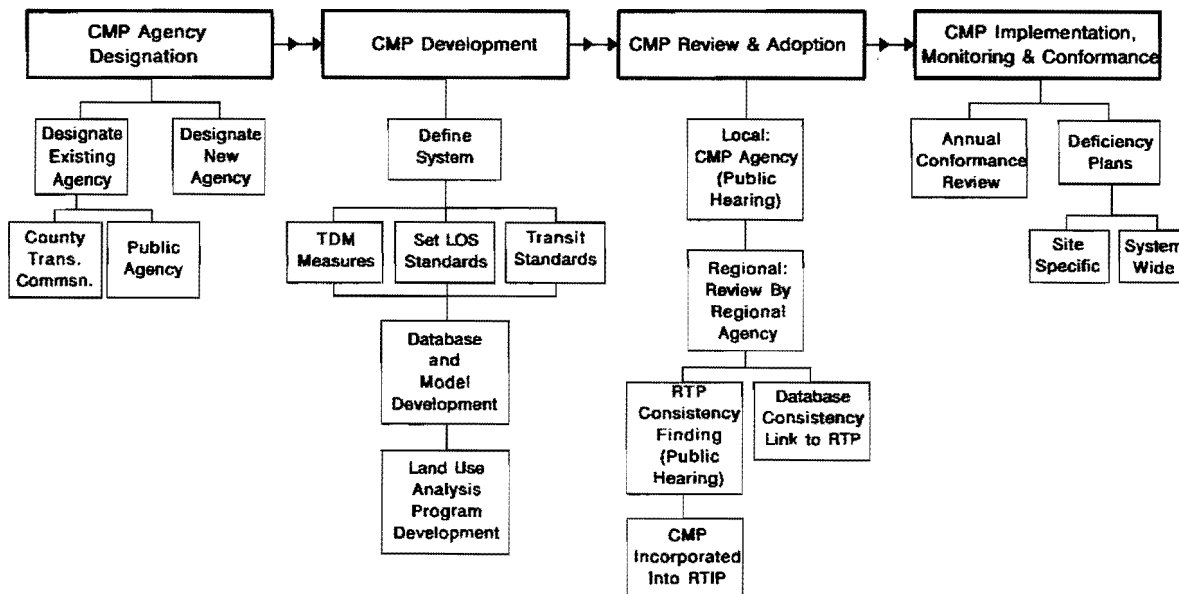SOURCE: Reference (62), p. 5.

Figure J-2.

The Contra Costa Transportation Authority (CCTA) is the sales tax agency for the county and is separately designated as the congestion management agency. As the sales tax agency, the CCTA is responsible for tax dispersement of sales tax funds to the county and the 18 municipalities within the county based upon 50% population and 50% road miles -- provided that the jurisdiction meets the adopted growth management objectives.

The Congestion Management Program (CMP) for Alameda County was developed during a 14 month process by several agencies in the Alameda County area. The Alameda County CMA is funded from the California gas tax, and the State Transportation Planning, Congestion Management, and Air Quality Funds (STP CMAQ).

The Bay Area Metropolitan Transportation Commission (MTC) is the metropolitan transportation planning organization for the nine counties within the San Francisco Bay Area. The MTC was challenged in becoming a model regional planning agency for the country with the passage of the ISTEA. Under the Federal Clean Air Act, the MTC was sued by the Sierra Club and Citizens for a Better Environment. The resulting three years of litigation forced the MTC to significantly modify their practices by bringing air quality issues to the forefront in their transportation planning and programming. The MTC staff reported that establishment of the county CMAs simplified their tasks since they now can work closely with the nine CMAs which in turn provide the detailed contact with the several local jurisdictions and interested groups within each county.

As an MPO, the Bay Area MTC is responsible for coordinating the nine counties in the Bay Area. It is the duty of the MPO to ensure consistency and compatibility at the boundaries of adjacent counties. In order to better address congestion management issues, the MTC staff reported that they believe that the MTC needs to play a strong role in developing a coordinated regional strategy to attack congestion and other related problems (e.g., air quality) from a multimodal perspective. It was also stated that, in the development of a congestion management system (CMS) for the Bay Area, existing county CMP's will serve as local level building blocks for the CMS. Facilities management programs developed at the state level will be coordinated for local implementation through the regional/MPO CMS mechanism.

CALTRANS-4 has indicated that they feel there are problems with the current organization dealing with congestion management. Individual cities and/or counties have selfish interests, and they fail to address development and land use issues on a scale larger than their own jurisdiction. The sooner counties and local jurisdictions begin to plan on a broader scale with a regional CMP, the more effective their actions will be. It is difficult however, for county CMAs to recognize the benefits of expenditures on projects not within county lines as being helpful to their individual needs.

CALTRANS-4 staff also indicated that they believe that a strong regional agency, such as the Metropolitan Planning Organization (MPO), is needed to promote and enforce uniform standards used in the evaluation and implementation of congestion management issues. This is especially true when a number of small cites or jurisdictions are involved. The Bay Area MTC indicated that the county CMAs are extremely helpful when working with numerous municipalities.

The Santa Clara County CMA area includes 15 municipalities, the county, and the transit system which is an independent county agency. However, the CMA can not withhold funds for the transit agency, if it is not in conformance. A traffic impact analysis (TIA) is required for all projects generating 100 new trips or more in the peak hour (passby trips are excluded from this threshold requirement). The CMA conducts an annual survey/questionnaire of all political jurisdictions each year to help identify any changes in the general plan or planning policies, site plans, subdivisions and building project proposals.

The Santa Clara County CMA has also established a technical advisory committee made up of one member from each city and alternates from each city. The members are typically the city planner or public works engineer. There are 15 cities represented along with the transit agency, taxing authority, and county water quality/storage agency. The committee contains several subcommittees covering areas such as land use, LOS modeling, transportation demand management, environmental issues, transit and CIP. Citizens are welcome to comment or complain to the committee.

The Commuter Network is also organized as part of the Santa Clara CMA. The Commuter Network is responsible for implementing a county wide transportation demand management program. The Commuter Network was created in January 1989 to help employers establish their own TDM programs by using the commuter networks staff of professionals. This network has now become essential with the requirements required by the Regional Trip Reduction Rule adopted in November 1992 by the Bay Area Air Quality Management District.
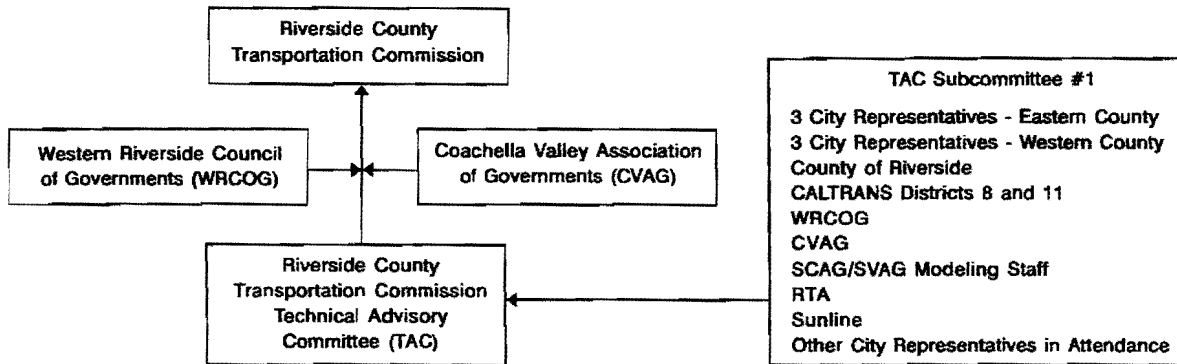
The San Joaquin County CMA was organized as a joint powers agency or board within the MPO. Ten board members are selected by their elected officials. Those selected are generally conservative in their viewpoints, but are still progressive. The ten board members consist of one representative from each of the six counties, two representatives from the city of Stockton, and two representatives from the San Joaquin County Board of Supervisors.

The interviewers found that the "rigid" approach was the most serious error in the early part of the Los Angeles County Metropolitan Transportation Authority CMP development. The legislature detailed what was to be done in great detail. The Los Angeles County MTA approached implementation as a prescription that cities were to take. They refused. After flexible goals were allowed and the cities were included in establishing those goals, the implementation went very well. This experience indicates that a toolbox of alternatives rather than a prescription is what is needed. The program must start by finding a common denominator and then building upon it. A prescribed approach is unlikely to be successful in every area. The data collection costs must be kept to a minimum, since cities have little money and data collection is low on the list of priorities. The system developed by the MTA addresses these requirements. Seventy stations on 1,600 kilometers (1,000 miles) of freeways and one station on two mile centers on the arterial street system to be counted once each year was agreed upon.

The Riverside County Transportation Commission was designated as the congestion management agency for Riverside County. Other agencies within the county, including city agencies, the Coachella Valley Association of Governments (CVAG), and the Western Riverside Council of Governments (WRCOG), supported the RCTC as the designated CMA. These agencies all had a role in the development of the CMP, and continue to play an important part in the implementation of the CMP. The organizational structure of the Riverside County TC is shown in Figure J-3.

FIGURE J-3. Riverside County CMP Organization
SOURCE: Reference (16), p. 1-3.

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┌─────────────────────────┐
│    Riverside County     │
│ Transportation Commission│
└─────────────────────────┘
            ▲
            │                                    ┌──────────────────────────────────────────┐
┌──────────────────────┐   ┌──────────────────┐ │         TAC Subcommittee #1               │
│ Western Riverside     │   │ Coachella Valley │ │                                           │
│ Council of Governments │▶◀│ Association      │ │ 3 City Representatives - Eastern County   │
│ of Governments (WRCOG)│   │ of Governments   │ │ 3 City Representatives - Western County    │
└──────────────────────┘   │ (CVAG)           │ │ County of Riverside                        │
            │              └──────────────────┘ │ CALTRANS Districts 8 and 11                │
            │                                    │ WRCOG                                      │
┌─────────────────────────┐                      │ CVAG                                       │
│    Riverside County     │                      │ SCAG/SVAG Modeling Staff                   │
│ Transportation Commission│◀────────────────────│ RTA                                        │
│   Technical Advisory    │                      │ Sunline                                    │
│   Committee (TAC)       │                      │ Other City Representatives in Attendance   │
└─────────────────────────┘                      └──────────────────────────────────────────┘
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The CMP developed for Riverside County addresses the differences that exist within the jurisdiction. Riverside County actually has three CMPs. One for the Eastern County Area, one for the Desert Area (Palm Dale and Palm Springs) and one for the Riverside Area. The Eastern County plan is almost entirely highway oriented. The Desert Area CMP is almost entirely highway and street oriented. The Riverside CMP includes Freeways, Transit, and Road and Street elements.

In San Diego, the Air Quality District, SANDAG, and CALTRANS-11 generally work independent of one another. There are really only two major players dealing with congestion management, the city of San Diego and CALTRANS-11. Little data are shared among the agencies. CALTRANS is not often asked to provide data. The traffic data are directly down loaded to the traffic reporting services. The city of San Diego or SANDAG could receive the data, but presently they do not. In addition, the Air Quality District does not think that freeway ramp control has an overall positive effect on air quality.

The San Diego Transportation Management Association is an association of businesses in San Diego and coordinate the transportation demand management requirements of the City of San Diego and the State of California. The members are predominately downtown businesses, but they are currently expanding their membership into the outlying areas. The San Diego TMA helps in the organization of the following specified events: bike day, ride share week ("Don't Drive Alone Day"), and monthly training sessions on ride sharing. The San Diego TMA advises their members on the TDM requirements and works on their behalf to develop workable TDM programs.

The regional growth management program (RGMP) is the primary element in SANDAG's attempt at congestion management. The CMS program is a part of the RGMP. All city and county land use plans are updated annually and integrated into SANDAG'S files. SANDAG does not expect ISTEA to have any effects in San Diego County. It is their estimate that only about 3% more funding will be available to San Diego County. That is a minimal increase in available funding. It is their opinion that ISTEA is a large increase in expectations with no money to really accomplish anything.

The relationship of air quality and transportation/land use tactics is a major concern to SANDAG. The Air Quality Control Board focuses on specific transportation tactics with an impact on air quality that is so small that the expenditure on them is questionable in terms of cost-effectiveness. According to the SANDAG Director, there is a need to integrate the air quality people in the decision process, but they must not dominate it.

The Air Quality Regulation Board (ARB) changes assumptions nearly every month. This leaves the public absolutely confused. Careful consideration must be given to investing money on fuzzy model data. SANDAG feels that there is a need to implement proven technology to reduce air pollution. Alternative fuels are one of the better ways to address air quality issues, and alternative fuels are part of the ARB's responsibility. However, the ARB focuses on transportation tactics and devotes little attention to the alternative fuels program.

SANDAG staff feel that past practices of using environmental impact statements on individual projects has not worked. It has become simply a "bean counting" exercise that consumes large amounts of money and accomplishes little. The staff suggested that a better approach is an environmental goal for the region. Individual projects are then approved on a brief statement that the development is compatible with the established environmental goals and the fact that appropriate traffic impact mitigation measures have been included in the project. This is similar to the railroad crossing Master Agreement and work orders used in rail road grade crossing improvements for many years.

Outside of California, several agencies have started preliminary organization of their CMS program. However, these agencies are about two years behind California due to the enactment of the California CMS legislation two years before ISTEA. Those agencies which began organization of their CMS program in response to the ISTEA have limited experience on what has and has not been effective. Many of their comments reflect programs which have worked well for them in the past and what they think will work well in their CMS program.

The Capital District Transportation Committee of Albany, New York (CDTC) is apparently very effective in implementing programs in cooperation with the local jurisdictions within its four county area. It also has an extremely effective working relationship with the NY DOT, both at the regional office level as well as with the state headquarters. This relationship was confirmed during the interview with the NY DOT personnel. The success of CDTC is apparently due to the following factors: 1) an extremely technically capable, although small, staff; 2) close and detailed contact and communication with local elected officials; 3) continuous contact and communication with NY DOT district and central office personnel; and 4) a credibility developed over a period of years.

The New York DOT indicated that "it is essential that it must be made clear where the CMS is located in the state DOT organization, which bureau is responsible, and who does what" (23) At the time of the site visit, the organizational structure of the New York

DOT CMS program was still under consideration. The New York DOT recently established the Goal Oriented Program (GOP). The GOP involves establishing DOT policies, practices, and procedures relative to the following four areas: pavements, bridges, safety, and capacity/mobility. With the passage of ISTEA, capacity/mobility was redesignated as congestion management.
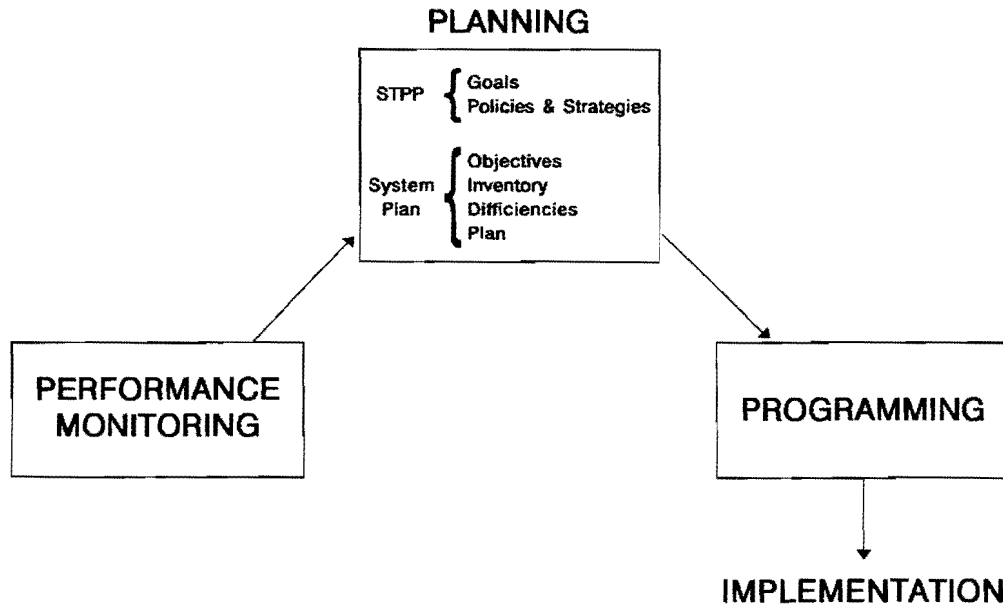
The GOP process "cuts across" the entire NY DOT central office structure. It should be noted that a Goal Manager is an Assistant Commissioner. Thus, goals are formulated under the direction of a high administrative official who is in a position to see that the necessary resources are available to successfully accomplish tasks and develop implementable goals.

The main goal of the congestion management GOP is to "maximize the reduction of vehicle-hours of delay (VHD)." Reductions in VHD are sought through TSM improvements, TDM actions, and capacity improvement projects (56). The CMS will be coordinated by the Systems and Program Planning Bureau within the Office of Planning and Program Management which is at the Assistant Commissioner level. The CMS unit will be the NY DOT administrative group that will deal directly with the MPOs. Also, it will be the focal point for CMS issues/activities involving other NY DOT units such as IVHS, mobility transit, TDM etc.. which are administratively located in other offices headed by an assistant commissioner and in the NY DOT Regions.

Organizationally, the Puget Sound Regional Council permits each city to complete their own data collection procedure. There is no general consensus on the way to measure congestion among the cities of the Puget Sound Regional Council. Each is going its own way in this regard. In addition, the community trip reduction policy is difficult to pull together. Mitigation fees are charged, but these funds cannot be used for transit service improvements. Capacity and saturation flow rates also differ among the various cities. They use different methods to define capacity. This causes problems at boundaries which the Regional Council must resolve. The land use interaction with surface transportation is being addressed under the growth management act.

The Washington Department of Transportation has outlined a system which will be used to address the 1991 Intermodal Surface Transportation Efficiency Act. This system is outlined in Figure J-4. The goals of this system include preservation of the existing transportation system, linking land use development with transportation system development, supporting international trade, promote a positive quality of life by ensuring mobility alternatives, encouraging public-private partnerships, protecting the environment, and ensuring the collection of appropriate revenues to support the transportation system (57). The system shown in Figure J-4 is designed to accomplish these goals by monitoring the existing system in order to develop efficient and cost-effective programs and projects. The State of Washington plan was fully discussed with the TMAs and they are reportedly in general agreement with it.
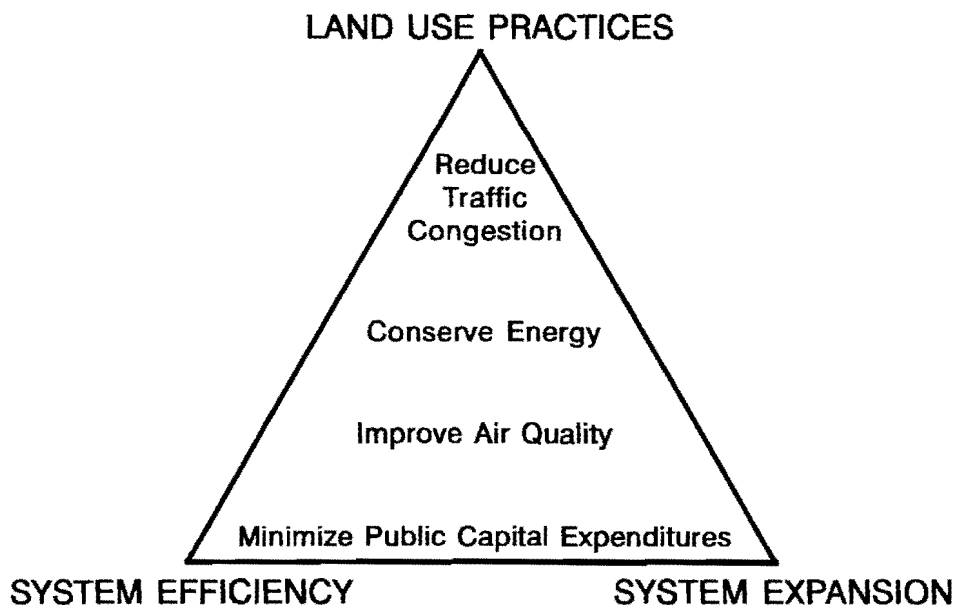
Figure J-4. Washington DOT Transportation Policy Plan

PLANNING

STPP { Goals
         Policies & Strategies

System   { Objectives
Plan   Inventory
             Difficiencies
             Plan

PERFORMANCE MONITORING

PROGRAMMING

IMPLEMENTATION

In order to combat congestion and improve mobility, the State of Washington has proposed three major areas of concentration: land use practices, system efficiency, and system expansion, as shown in Figure J-5. All three of these areas can have a significant

Figure J-5. Mobility: A Three-Sided Equation
SOURCE: Reference (58), p. 5.

LAND USE PRACTICES

Reduce Traffic Congestion

Conserve Energy

Improve Air Quality

Minimize Public Capital Expenditures

SYSTEM EFFICIENCY   SYSTEM EXPANSION

impact on improving mobility. Land use practices include the growth management and access management acts already in place, while system efficiency includes TDM and TSM strategies to reduce single-occupant vehicle trips (58). Land use practices and system efficiency are the most cost- effective solutions, so a major emphasis has been placed on these two areas.

In addition, the State of Washington passed a growth management act in 1990. Under this act, the state is divided into seventeen regional transportation planning organizations. Each organization has responsibility for implementing the growth management strategy of the state act. The growth management act requires local governments to make development regulations (zoning, subdivision, building codes, etc.), develop land use plans, designate and protect natural resources, and target designated urban growth areas. Other requirements include developing policies relating to affordable housing, fiscal impacts, county-wide economic development, and county-wide transportation facilities and strategies (59). The plans for implementation are now being developed and are due in June 1994. A very limited access management policy is also in place in the State of Washington, but it was reported that it has not been very effective.

It was noted that when an agreement is required, it can be accomplished in a short time in the State of Washington. They cited the conformity rule as an example. The policy was written and agreed to in six months after the Legislature instructed that it should be accomplished. Policy in the Puget Sound Area is to allow high levels of congestion to encourage transit interest and use. Bus lanes on streets are used and the Washington Transportation Policy encourages the use of public transportation.

The Washington DOT has also placed great emphasis on the background air quality levels in non-attainment areas. They indicated that they have found that measuring air quality changes due to transportation policies is difficult and the background levels in the area are not well quantified. The program represents an integration of travel demand management, access control, and air quality through a well thought out system. This system involves goals, policies, and specific objectives for the rural state highway system. The statewide growth management law is a model most states could adapt to their own circumstances.

In the Chicago area, the Regional Council of Mayors reportedly is very effective in dealing with a variety of issues, including transportation. It is expected that they will also be effective in dealing with congestion management issues. Mayors and other officials of municipalities which are on or near the boundary of an adjacent Regional Council participate in the activities of that council as well as the Regional Council in which they are located. Full participation, except for voting on the expenditure of funds, is involved.

However, a comprehensive congestion management program has yet to be implemented in the Chicago Area. Management and improvement of the existing freeways is related to accidents and physical condition rather than congestion. Treatments on surface

streets (such as intersection improvements and signal coordination) are precipitated by local concerns and perceptions. Definition and implementation of the strategic regional arterial system is in response to improving regional mobility, rather than as a congestion management program.

An intergovernmental agreement in Chicago between the several concerned municipalities and the county and between the Regional Council and IDOT were effective in the upgrading of Central Lake County Expressway, Route 53. Effectiveness is attributed to the fact that this route involved near term planning and IDOT was prepared to begin construction immediately. Similar agreements have not been effective in controlling land development when the subject route involved long term development at some indefinite future time.

The toll roads in Chicago are controlled by an independent authority. During the site interview it was stated that CATS and other agencies have difficulty in obtaining cooperation with the toll road authority. It is also expected that future freeway type facilities in the Chicago region will be built as toll roads. How to incorporate and the extent of cooperation in monitoring toll roads as part of a total regional CMS is a concern.

The North Carolina DOT does not presently have a CMS or a program for monitoring congestion. The NC DOT has, however, organized three task forces relative to congestion management (67). These task forces include the following.

1. Task Force on Incident Management in Project Planning.
2. Task Force on Information Management. To date, this group has devoted their efforts to software systems and reportedly favor adoption of the data system distributed by the ORACLE Corp, which is used by the KY DOT.
3. State-MPO Task Force on Congestion Management. This task force had not yet met at the time of the site visit.

State-of-the-Practice of the Project Evaluation Process for MPOs and CMAs

The selection of congestion management projects for the Contra Costa County Transportation Authority is based on a complex prioritization process. Criteria used in the project selection process include geographic equity, leveraging of state and federal funds, congestion relief effectiveness, project readiness, and environmental impacts. Once selected, the current process of implementation is through project proponents (generally a local jurisdiction, city, county, or public agency) who oversee the environmental clearance, project design, and construction. An on-going effort is taking place which consolidates and integrates existing management systems and CMS into one agency. The results of this consolidation have been successful to date.

Prior to the passage of the ISTEA, the transportation projects within the Bay Area MTC's jurisdiction were funded through a number of individual processes. The ISTEA

empowered the MTC to obtain funding for projects which met multiple objectives. With the recent adoption of the Bay Area MTC's _1993 Transportation Improvement Program_ (TIP), funds became available for 225 projects. These projects are aimed at improving all classes of roadways through all modes of transport. There are three types of criteria that were used by the MTC to develop the Surface Transportation Program (STP) and the Congestion Mitigation and Air Quality improvement program (CMAQ) in the Bay Area. These criteria are screening criteria for candidate projects, scoring criteria to evaluate projects based on relative merit, and programming principles that ensure that the program of projects will increase mobility, clean the air, leverage the most state and federal resources, and be equitable (61, 62).

The Bay Area screening criteria for candidate projects included five basic groups of requirements: 1) consistency requirements, 2) financial requirements, 3) project specific requirements, 4) air quality requirements, and 5) Americans with Disabilities Act (ADA) requirements. The consistency requirement requires that the projects meet all mandates of the ISTEA and follow the interim guidelines published by the U.S. Department of Transportation. The financial requirement made sure that projects had reasonable cost estimates and were supported by adequate financial plans. The financial plans included identification of all sources of funding, logical cash flows, and sensible project phasing (61,62). Projects are also required to meet the bid limit set by the MTC.

The project specific requirements define the conditions under which projects may be submitted for approval. All projects must be clearly defined including project limits, intended scope of work, and project concept. The projects must also be eligible for either the STP or CMAQ programs. Other project specific requirements include that projects must be well justified, have completed application forms, have sensible phasing, and be advanced to a state of readiness for implementation by the end of 1994.

The air quality and ADA requirements are not as detailed as the other three. Certified air quality documents are not required. However, if environmental documents are submitted, they must conform to the most recent MTC regulations. ADA requirements usually only apply to transit projects. All transit projects must comply with the ADA, as well as any road projects which include items such as call boxes or anything which must be accessible to the disabled.

All projects which pass through the screening process are then evaluated with the scoring criteria. The scoring criteria were intended to favor projects which meet a documented need, are cost effective, accommodate multimodes, and comply with the most recent adopted plans, the ISTEA, and the CAAA. Projects were scored on a scale of 0 to 100, with the highest scoring projects given the priority to be implemented (61, 62).

Following the scoring criteria, projects must then be screened with the programming criteria. The programming criteria is intended to ". . . produce the best possible program of projects that will benefit the Metropolitan Transportation Systems (MTS) regardless of

mode. In addition, the program as a whole is required to conform to the mandates of the federal Clean Air Act and be responsive to the directives included in relevant state Clean Air Plans." (61, P. III-A-21)

The Alameda County CMA selects its congestion management projects by using its long range plan to identify high priority improvements and management strategies such as pricing and land use agreements. The CMA does, however, have state authority to require trip reduction programs and land use programs of the local government.

In considering projects involving new facilities (such as freeways, toll roads, and HOV lanes), several problems exist. Namely, they require a large investment, have environmental constrictions, and there are not too many places available in Alameda County to add new highways. Problems for freeway construction are mainly environmental. Toll roads are still under construction, while HOV lanes for arterials have not been considered yet. The main concentration of the focus has been on freeways. Since the CMP has only existed for two years, sufficient time has not passed for successful implementation and evaluation of projects.

The San Joaquin County Council of Governments project implementation plan is based on their definition of congestion; LOS "D" is the break point between congested and uncongested flow. When the LOS of a route with the CMP falls below "D", or is projected to fall below "D", the jurisdiction in which the facility lies is responsible for preparing a deficiency plan which explains how the problem will be mitigated. The jurisdiction has 90 days to prepare a deficiency plan once the segment has been identified as being congested (13). To date, the San Joaquin County COG has not yet issued a call for a deficiency plan. Therefore, there are no current standards in the implementation process. The full impact of a Congestion Management System (CMS) on their deficiency plan process has yet to be discovered.

The Los Angeles County Metropolitan Transportation Authority coordinates congestion management projects, but all agencies participate in monitoring and prioritization of the projects. The authority needed to implement programs comes through the state CMP legislation tied to transportation funding. California has a seven year State Transportation Improvement Program (TIP). Therefore, projects selected this year will not go to construction until the year 2000 or 2001. Thus, no implementation has taken place to date.

Project selection for the Riverside County CMS program is done at the local government level. The major innovation in the Riverside County Transportation Commission CMP is the use of a fixed mitigation fee approach to cost of site development impacts. The fee is based on the trips attracted by the site. The developers like the fixed fee approach because they know up-front the fees involved. The cities like it because all developments, whether it is the first development in the area or the last, pay the same fee. The money generated is used as the local share funding to match state and federal funds available to mitigate the impacts of the development.

The congestion management legislation in California requires local agencies to mitigate roadways with deteriorating LOS. This can be accomplished by increasing capacity or utilizing other modes of transportation. Congestion management projects are, and will continue to be, implemented according to CMP guidelines. A 1.5 average occupants per vehicle rate (AVR) is targeted to be achieved by 1999. This rate is aimed at individual businesses and not the entire traffic stream.

As an illustration of what can be achieved, SANDAG established a $45 benefit for its employees if they did not drive to work for at least 18 days per month. The results were that only 26% of the employees now travel to work in single occupant vehicles. This percentage is aided by the fact that SANDAG is located downtown with bus access. SANDAG will probably not get involved in project design under ISTEA. That will remain at the local government level.

Outside of California, local agencies are just beginning the implementation of CM programs. Therefore, most policies relating to project selection and implementation currently in use have been used for years before the passage of the ISTEA. The project selection processes discussed below include the current methodologies and are not necessarily the procedures which will be used once a congestion management program has been implemented.

The St. Cloud APO makes recommendations to 16 political jurisdictions (3 counties and 13 municipalities), and many decisions are highly political. The agencies reportedly do not have advanced ordinances and standards relating to access location and design or site development. However, any roadway improvement beyond 2-lanes (one in each direction) within the city of St. Cloud must be voted upon in a binding referendum. Even the addition of a turn bay must be approved by a majority casting ballots. All projects must be approved by the citizens of St. Cloud before they are implemented.

As part of the Surface Transportation Program (STP), the Bi-State Regional Commission must evaluate candidate projects in order to receive federal funds. The projects are evaluated based on four categories of criteria. The first category is LOS. LOS values are identified for each project based on the existing volume/capacity ratio. In addition, a ten-year projected traffic volume and the project's ability to reduce traffic congestion are used to evaluate the LOS criteria. The second category used in the Bi-State RC process is safety. The criteria used to evaluate safety considerations included total number of accidents, accident severity, and accident rate. Physical pavement condition is the third category, which includes surface type, surface condition, existing volume, 10-year projected volume, and number of lanes. The fourth category is special considerations and does not apply to all proposed projects. This category includes accident reduction, air quality considerations, automobile alternatives (such as sidewalks, bicycle trails, and transit), and economic development.

Figure J-6. The SRA Implementation Process for Routes Under IDOT Jurisdiction
SOURCE: Reference (30), p. 15.

PRE-PHASE I (ROUTE STUDY)	PHASE I/ DESIGN REPORT	PHASE II	PHASE III	PHASE IV
PLANNING	**PRELIMINARY DESIGN**	**FINAL DESIGN**	**CONSTRUCTION**	**POST CONSTRUCTION**
1. Data Collection 2. Test Alternatives 3. Local Coordination 4. Environmental Screening 5. Recommend Improvements 6. Public Hearing	1. Preparation of Preliminary Plans 2. Public Involvement 3. Environmental Studies/Mitigation 4. Public Hearing	1. Preparation of Contract Plans 2. Community Coordination 3. Environmental Mitigation	1. Implementation 2. Community Coordination	1. Environmental Monitoring 2. Land Development/ Access

For all routes selected as part of the Strategic Regional Arterial (SRA) System of the Chicago Area Transportation Study (CATS), routes studies must be conducted. The route studies will recommend comprehensive short and long-range improvements for each route. The route studies included data collection/evaluation, route analysis, environmental issues, construction cost estimates, local involvement and coordination, and the final route improvement plan/report. This route study report must be completed before a project is considered for implementation. The route study is the first step in the implementation process, as shown in Figure J-6.

Currently, all projects for the Capital District Transportation Committee are selected based on the procedures indicated in the Transportation Improvement Program (TIP) (63). Each project is required to meet three screening criteria at a minimum: consistency with the Long Range Plan, local land management, the plans of adjacent jurisdictions, and the ISTEA mandated factors; financial reasonableness; and project specific eligibility and justifications. After meeting these criteria, a project goes under further review and evaluation based on merit (cost-effectiveness, intermodalism, qualitative aspects, data requirements, etc.) and programming criteria/principles (regional goals, mobility, transit, pavement, bridges, etc.). Projects are selected based on these criteria and then funded for implementation.

Project selection for the Puget Sound Regional Council is and will be handled using the VISION 2020 report. It focuses on people moving but makes special provision for needed overlays and safety improvements as needed to protect the investment in the highway system. Otherwise, only projects involving increased vehicle occupancy strategies will probably be funded.

All proposed projects in the Charlotte DOT's jurisdiction are ranked by staff of the Charlotte DOT, the City Engineering Department, the County Engineering Department, and the Charlotte-Mecklenburg Planning Commission using the following ten criteria: Safety,

congestion, benefit/cost ratio, neighborhood through traffic, redirection of growth, energy/air quality, job accessibility, business district/development enterprises area, accessibility to central city, and quality of life (64). The Charlotte DOT identified 76 unfunded improvements needed by 2005 to meet projected auto travel. These projects were in addition to the 19 thoroughfare improvements already funded by Federal, State, local and private sources.

Project requests for funding by the 2005 Charlotte Transportation Plan are then evaluated by the Charlotte DOT according to the following priority ranking system (65): First priority -rehabilitation or maintenance of existing facilities; Second priority - replacement of existing facilities; third priority - expansion of existing facilities; and fourth priority - new facilities. Several reasons were given for this policy, including to ensure that the existing infrastructure is maintained and replaced as needed.

CALTRANS-4 has a coordinator working with each county's CMA. Through the coordinator, CALTRANS-4 submits projects which they have an interest in to the CMAs and also solicits projects for the counties to work on. Congestion management projects are selected by the CMAs and then entered into competition with other projects for inclusion in the area plan. Selected projects go through funding, development and construction processes as part of their implementation. All of the funding for these projects comes from funding sources such as CMAQ and ISTEA. A Project Study Report is required before the funding of any project is approved. The Study Report details sources of revenue for the project, environmental issues, partners involved in the project, and a range of logical alternatives. Also included in the report is the project scope, schedule and total cost. A draft of the report is reviewed by CALTRANS-4 and by the county.

For the New York DOT, projects must by justified on the expected reduction in excess vehicle hours of delay. For each $1 million, a project must show an expected reduction in excess VHD. The criteria are 25 VHD per $1 million for upstate regions and 50 VHD per $1 million for downstate regions. Individual projects may fall below this criteria so long as the aggregate average of all projects equals or exceeds the required VHD reduction.

In TMAs, the Washington DOT leaves decisions up to MPOs regarding project selection. The Washington DOT is a member of each MPO board and indicated that the DOT will abide by their decisions. A new project prioritization program is being prepared that addresses the growth management and air quality policies adopted.

Policy/Funding Issues

The allocation of funds to mitigate deficiencies is an issue that was raised in a few of the site visits - most notably Colorado. It is expected that the selection of an unacceptable level of congestion and comparison of this "standard" with existing conditions will result in identification of deficiencies (i.e. roadway segments with unacceptable levels of

congestion). The priority for mitigation (degree of deficiency) may be easily established by the relative values of the measure of congestion used by an MPO or state DOT. Capable lists of deficiencies might be developed for the other management systems. The dilemma, then, is "how to make decisions relative to the expenditure of funds in a financially constrained program to correct deficiencies in the various areas such as intermodal, congestion, safety, pavements, and bridges?" Presumably, these decisions would be made in the metropolitan planning process, and the development of the TIP or STIP. The question(s) raised in some of the site visits were: How? What criteria should/can be used in a financially constrained program? How can the deficiencies in the various identified management systems be resolved through the metropolitan planning process or the statewide planning process.

If funds are available to correct every deficiency, then a problem does not exist. However, this is rarely, if ever, the case. Thus, it is in the interest of the agency to maximize income by looking as bad as possible in areas which are of the greatest importance in the allocation of Federal highway funds. For example if 50% of the weight in funding decisions is based on bridge deficiencies, then in evaluating deficiencies, bridges would be evaluated more critically say than another component which is weighted less heavily. Therefore, if categorical or formula funding is not used in the allocation of funds and the deficiencies identified in various management systems are used as the basis for allocating funds, the evaluation criteria for all five basic management systems must be established on a national basis to ensure a level playing field for all teams.

The allocation of available funds on a formula basis with adequate instruction on the proportion of funding that is to be directed to the local government level and how that allocation is to take place is preferable. The local governmental unit can then allocate the funds available between the various types of deficiencies in accordance with an approved plan to meet the stated congestion, environmental, and infrastructure goals.

Toolbox

Several recently published resource documents provide evaluations of several potential strategies for use in a congestion management system. The interested reader should request copies of these documents for further information. These reports include an evaluation of TDM/TSM effectiveness by the Pima Association of Governments (52) and the ITE seminar handbook for implementing TDM programs (66).

In addition to these documents, several agencies reported unique and effective programs currently implemented in their jurisdiction. The Riverside County TC reported that the following six unique TDM programs are underway in Riverside County.

    1) A booklet of coupons is given to all persons participating in ride sharing programs. Local businesses provide funds for food, discounts, fuel discounts, auto services, and personal services.

2) For 60 days, the RCTC provides free commuter buses to Orange County for any interested Orange County employer. After 60 days, the employer and the participants must work out the cost issues to continue the bus services. The employer pays for unfilled seats on the prorated per seat cost.

3) The RCTC also pays for the first three months of operation of any vanpool. After the initial period, the operation must become self sufficient.

4) The RCTC has also worked out agreements to share the cost of a telecommuting center. In addition to private funding, the RCTC and the State of California each invested two hundred thousand dollars to create the center. The objective is to reduce the number of trips being made to LA and Orange County. A report on the success of the center is expected in June or July of 1993.

5) The 1/2% sales tax funds have been used, in part, to connect Riverside to the LA fixed rail system. This system is a substantial portion of RCTC's highway trip reduction program.

6) The RCTC worked with a local recreational vehicle dealer to provide a mobile home to use as a commuter store. It travels around the Pasadena/Riverside area stopping at places where people gather and providing transit and ride sharing information.

The San Diego Association of Governments stressed that transportation officials must fund improvements that have been proven to work well. For example, they suggest the following.

1) Ramp metering: It does create an air quality "hot spot" at the ramps; but overall, the benefits of ramp metering far outweigh the negatives in both a congestion management sense and in an environmental quality sense.

2) Traffic Signal Computerization/Coordination: The program has a much more positive impact on air quality than the use of public transit vehicles. This is especially true when the older transit vehicle engines are used.

3) Providing for continuity of arterial streets: In the North County area, between I5 and I15, cul-de-sac type development has not provided for the continuity of arterials. As a result, very short trips are made on the freeways. This substantially impacts the congestion on the freeway segments. The transportation officials for regional transportation agencies must ensure that the arterial streets and roadways are continuous and function well. The North County area has had a 3-4% per year growth in past decade and the transportation infrastructure has not kept up with the demand. Also, the number of trips has increased more rapidly than population over the past decade. It seems to have flattened out in recent years.

The Washington DOT travel demand management policy spells out the TDM goals. Carpooling, van pooling, express bus (subscription bus), alternative work hours, and telecommuting were required elements of the state legislation. The Washington State

Energy Office ran a demonstration program in this area for evaluation purposes. The final report should be available in the near future.

The Charlotte DOT and the City of Charlotte coordinate to provide the following transportation management programs: carpool matching services, vanpool program, preferential parking spaces for carpools/vanpools, Charlotte transit express service, park-and-ride facilities, guaranteed ride home program, uptown transportation council, HOV facility planning, US 74 HOV facility, and the Central Avenue corridor signal preemption system.

The Puget Sound Regional Council has recently experimented with a telecommuting demonstration project. The interested reader should obtain a copy of the evaluation reports available for this project (67, 68).

Agency Comments

Many agencies had specific ideas regarding how congestion management activities should be structured, including what they thought would work and what would not. The following comments were made by representatives of the various agencies relative to the congestion management system structure during the interview process.

- Several interviewees with the county congestion management agencies indicated that the California legislation falsely assumes the availability of extensive traffic operations data.

- The Contra Costa County Transportation Authority personnel indicated that the evaluation of roadways, and the resulting recommendations based on LOS, is a very politically charged issue in many communities. On one side of the argument are those people who do not want their community to grow. In order to discourage infringing development, these people oppose the upgrading of roadways within their community. When other people want their community to expand, it leads to a heated debate regarding the criteria used in assigning LOS grades.

- The Alameda County CMA staff recommends that who sets-up/develops models for allocation of resources be clearly defined and that the costs of a data base and model maintenance be recognized. Avoid proliferation of computer models. The county is a good local-regional interface, but ultimate coordination and approval of the CMP is with the MPO.

- The Santa Clara County CMA staff recommended that deficiency plans be developed on a subarea basis and that subplans include specific mitigation actions and implementation procedures/strategies.

- Comments received indicated that changes are needed in the San Joaquin County Council of Government's interagency or institutional organization to better address

congestion management issues. The County Council needs to clarify its working relationship with the San Joaquin Valley Unified Air Pollution Control District, which implements state and federal clean air acts. The Air District and the County Council have overlapping responsibilities, such as trip reduction.

- The Contra Costa County Transportation Authority staff indicated that congestion is forecast to worsen in the future, despite implementation on new projects and programs. Continued auto-oriented development, and lack of accountability for local land-use decisions are major concerns. On the positive side, transit use and carpooling can be increased, if congestion for single-occupant autos becomes worse.

- Minutes of the California state-wide CMA meetings are not kept. However, several surveys of critical needs in Congestion Management have been conducted. The CMA FORUM and state-wide CMA meetings have been one and the same for the last two years. The biennial update of the CMP is a workable response time. Annually is too frequent to be cost effective and three years is too long.

- The Los Angeles County MTA feels that the CMP does not deal with access control or city street geometries. Any mandatory street design controls would be very difficult to sell at the local level. The reason for a regional set of guidelines is the desire of developers to have a common set of rules everywhere in the metropolitan area.

- The Los Angeles County MTA is very concerned that in the implementation of the ISTEA, the CMS requirements not destroy the two years of work that has gone into their plan.

- There has not been a conflict between air quality goals and transportation services goals in Los Angeles, but the measures used in the two are in conflict. The coordination of land use, transportation and air quality consideration in CMP decisions is summarized as a general "they should talk to one another" the first year. It is anticipated that the requirements will be mandatory in the second year.

- The Riverside County TC feels that a large and diverse metropolitan areas (LA-Riverside-Pasadena, etc) must have a strong association of governments. Their task is to review proposed developments in the various jurisdictions that have been approved in the last quarter. Quarterly meetings are sufficient to give the elected officials an overview of the developmental issues.

- Problems that exist between counties also exist between cities -- except in a different way. A development in one city may create an impact in an adjacent community which is identified in the Environment Impact Report. Presently, the adjacent city may not know of the impact, until it actually comes about. The RCTC tries to identify these problems and advises all parties that they exist. Mr. Blackwelder,

Deputy Director of the Riverside County TC, suggested that the environmental impact report should require these issues to be highlighted; and the adjacent city should be notified of the impact of a development outside their boundaries *before* the formal approval of the development. This allows arrangements for sharing the mitigation fees involved to be agreed upon by both the parties. He also suggests that when conflict between the local governmental unit develops, the access to non formula funding should be curtailed until the conflict is resolved.

- CALTRANS-11 personnel indicated that a toolbox approach toward combatting congestion, as opposed to specific measures, is probably better for all concerned. That is, the congestion management program needs to consider a wide range of potential actions when developing a congestion management program. Moreover, a successful program needs to include a program of actions appropriate for the specific local situations.

APPENDIX K

STATE-OF-THE-PRACTICE:
IMPLEMENTING AND ADMINISTERING THE CMS

All references cited in large underlined numbers in this Appendix are identified in the References section beginning on page 29 following Chapter 3.

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When beginning to implement a congestion management system, many agencies have discovered problems which seem to conflict with the purpose of the CMS. State and local laws, requirements, and ordinances which have been in place for years for other purposes, now pose problems for the agencies attempting to implement a CMS. Several agencies indicated during the site visit problems which have arisen or they expect will arise regarding implementing and administering the CMS. Many California agencies also expressed concerns over the current California legislation and how it can be improved. This chapter summarizes these concerns and identifies the issues involved.

State Constraints

The California legislation established congestion management agencies to address congestion issues and monitor congestion levels. Financial incentive for local participation comes from a gas tax, a portion of which is distributed to local jurisdictions that comply with the requirements of the program. Currently, local California governments have control over transportation and environmental decisions. Many of these decisions are based on political considerations and public consensus. The California State Legislature also requires each county to provide an approach which details their plan to control land use and congestion measurement by a LOS method, a transit program, a trip reduction program, and a land use program.

The current California legislation is often incompatible with the reality of technical problems. The Bay Area Air Quality Management District reports that 75 to 300 million dollars are required to meet the current air quality standards; that is as much as $175/employee for mitigation. However, the Bay Area Metropolitan Transportation Commission (MTC) estimates that full implementation of traffic control measures would improve air quality by approximately 1%.

The Bay Area MTC and several county CMAs also expressed that the California Legislation is poorly structured. The following examples were given to highlight the legislation's deficiencies:

1. Exclusions permitted in the legislation;
2. Level-of-service as the measure of congestion and for the monitoring device;
3. Sanctions with existing vs. forecast congestion;
4. Although the legislation only requires annual monitoring of the system, the plan must be updated biannually; and
5. A definition of "primary arterial" is never given.

New California legislation (S.B. 1435, Senator Knapp) will make a better connection between ISTEA, CMP/CMA, Long Range Transportation Plan, and Transportation Improvement Plan (TIP). Senator Knapp introduced the original Congestion Management Program legislation.

Alameda county will use the Metropolitan Transportation Commission network for implementing the land use program. Land use is primarily controlled through impact mitigation fees. The Alameda County CMA is responsible for both the CMP and the Long Range Transportation Plan. If a county has a trip reduction program as part of the CMP, they have a one-year grace period with the Bay Area Air Quality District (until June 1994 instead of June 1993).

The State Treasurer is obligated by California Law to withhold funding for any item in the Transportation Improvement Program (TIP) not in conformance with the CMP. The projects are approved or disapproved by the Alameda County CMA. The city must also be in conformance with the CMP, where conformance is defined as making progress or attempting to make progress. Implementation of the CMP will be amended to the Long Range Transportation Plan.

California law also requires that roadway elements remain permanently in the system after once being included. The Southern California AOG feels this requirement is worthwhile. Otherwise, the city will just drop the segment off the system when the proposed development creates a significant change in the traffic on the previously defined system. This would require the developer to pay for mitigation treatments under the CMP. However, the San Diego Association of Governments feels this requirement has a negative impact on the selection of a CMP network. More flexibility in the legislation would allow the CMS Responsible Agency, in co-operation with all interested parties, to make the decision to insert or delete links to the CMP network.

California law also specifies that trips can only be counted in the county of trip origin. Thus, a large development can take place just over a city boundary in which most, if not the entire, impact is in another county. This way the developer has no mitigation fee since the generated trips can not be counted. This feature of the California law was mentioned repeatedly during the California site visits.

The staff time required to administer regional congestion management for the Southern California Association of Governments was 50% of one person for the first year including the monitoring activities. It has dropped to about 25% in recent months. In addition, there is insufficient funding to integrate the CMS data systems with the other data bases. The Southern California AOG feels this is not a high profile task, but takes a great deal of staff time. Some funding needs to be made available for this task at the operating level.

Another major institutional concern in Southern California is that VKT (VMT) has been uncontrolled since the 1940's. Congestion management to maintain the LOS that presently exists will fail because 350,000 persons move into the Los Angeles area each year. If this occurs, then VKT (VMT) must increase and congestion must get worse. The Southern California AOG feels that the program must combine growth management and trip

reduction targets to be effective. It would be a good idea to tie the CMP funding to the growth rate of the area.

Washington State law requires a 15%, 25%, and 35% increase in average vehicle occupancy values at the work site by 1994, 1996, and 1998, respectively. Therefore, the additional data needed includes vehicle occupancy data to use as a base. There is also a required reduction in the VKT (VMT) of 35% in the State of Washington. This reduction is determined by the following method.

$$VMT = \frac{(Number\ of\ cars\ arriving\ at\ work\ site) * (Distance\ they\ drove)}{(Number\ of\ people\ working\ at\ the\ site)}$$

Congestion on rural roadways presents different problems than those experienced in urban areas. This issue has received little attention to date. NC DOT presently identifies congested routes on rural areas through the public hearing process and public comments. Some better method is needed to identify areas of existing congestion which occurs on weekends in many locations. Also, some method is needed to identify rural locations that can be expected to experience congestion in the future. Trend analysis and extrapolations of traffic volumes does not explicitly consider population changes, industrial development, or changes in activity patterns. Some more sophisticated method (State-wide travel model) is needed.

The Charlotte DOT noted that funding from State and Federal sources for transportation planning are very limited. The Charlotte DOT only gets about 15% of its funds from these sources. Therefore, about 85% must come from local sources. In addition, the Charlotte DOT feels that transit should be funded by all jurisdictions served by the system, not just the city of Charlotte.

The Pikes Peak COG noted that the Colorado tax limitation law poses a funding problem. In the last fiscal year, the legislature found that Colorado Springs collected $1.8 million in excess taxes. The State is currently taking action against the city. In view of the tax limitations on the city, citizens in Colorado Springs are questioning the use of $4 million in general revenue funds (2/3 of the transit system cost) to support Spring Transit, which is owned by the City of Colorado Springs.

Local Constraints

All jurisdictions within Contra Costa County must adopt a Transportation Demand Management (TDM) Ordinance consistent with certain Contra Costa Transportation Authority policy requirements. These requirements apply to all employers, development projects, and building complexes with more than 100 employees. Each jurisdiction will implement a TDM program with the intent of achieving an Average Vehicle Occupancy (AVO) of 1.3 by 1997. A TDM coordinator will be appointed to administer the TDM program. Annual reports shall be filed within each jurisdiction indicating the current AVO.

Upon implementation of the TDM program, each jurisdiction will be required to monitor: compliance of employers, the types of development projects approved and building complexes; develop and implement an information program on transit and ridesharing for its residents; and, provide penalties for any employers, development projects or complexes that do not abide by the standards in the TDM ordinance.

Deficiency plans must be prepared by member agencies (each municipality) of the Santa Clara CMA. The California State Legislation requires location specific deficiency plans. The Santa Clara CMS recommends doing a subarea deficiency plan including actions and implementation. The deficiency plans will be developed within each city (10 areas in San Jose for example) and subregions of the county.

Presently, developers are moving from the center city to the suburban areas where the CMP requirements are less critical. There is a need for a uniform set of guidelines for the entire metropolitan area and more stringent CMS requirements in suburban areas. The California CMP also does not recognize that the older parts of the city have a large increase in population over time. This comes with an increase in VKT (VMT). There is no new development to trigger a review under the CMP.

The ordinances of the city of San Diego require an Average Vehicle Ridership (AVR) for all businesses that employ 50 people or more. The target was to be reduced to 40 people this year, but has been delayed because of the conflict between SANDAG and the Air Quality District.

The major concern of the San Diego TMA is the required subsidy for transit users, ride share participants and bicycle riders. The Ordinance requires a $24 payment (50% of cost of transit fares) each month to each transit user. This salary supplement goes up to $100 per month in the future. A firm with 300 employees would pay $63,000 a year at the current $24 rate when their average vehicle occupancy is 1.5 rather than the 1.7 target value. Ms. Perkins, director of the San Diego TMA, hopes that the federal guidelines will reduce the required business subsidy to ride sharing activities.

In addition, the Air Quality District of San Diego requires extensive record keeping by every business in the San Diego area. In addition to the changes in employee usage of alternative modes, these records include all of the incentives offered or awarded in connection with attempting to meet the air quality standards for a period of at least five years. Ms. Perkins hopes that the CMS guidelines will not require any unnecessary record keeping for the individual businesses.

SANDAG has noted that it is difficult to get business persons to be interested in ride sharing when the guidelines mandated by either the Air Quality District, SANDAG or the City of San Diego are modified on such a frequent basis. Basically the businesses feel that until the Air Quality District, SANDAG, and the City get together on a common realistic goal, they will wait on implementation of TDM alternatives.

The need for a qualified technical staff is a significant problem in conducting urban transportation/modeling studies. The additional effort needed to implement and administer CMS will produce additional needs. All but the largest MPOs will have a staffing problem. A core staff, such as provided in the NC DOT can provide this capability; however, the supply of professionals with the necessary skill is limited and not being produced in sufficient numbers by the universities.

The NC DOT provides modeling/planning support for 17 MPO areas. The NC DOT staff consists of a branch manager, 5 unit leaders and 30 engineers with modeling experience. This provides a capable core staff so that technology is not lost due to personnel changes. However, 3 or 4 persons leaving in the past year resulted in some loss in staff capability as new staff must be trained and existing staff assigned new responsibilities. Such changes, especially in a staff of one or two transportation specialists is disruptive. It was stated that even the Charlotte MPO, the largest in the state, is not self-sustaining in its transportation planning/modeling capability. This points toward the need for a highly qualified transportation staff.

The St. Cloud APO has proposed to require developers to submit a Traffic Impact Report for their proposed development if the proposed land use has a trip generation rate of 100 or more new peak direction trips. The purpose of the report is to identify the impacts and effects on LOS which are likely to be created by a potential development. In addition, the report should identify whether or not improvements will be needed to insure safe ingress and egress from the proposed development, maintain adequate street and intersection capacity on roadways adjacent to the proposed development, and eliminate adverse effects on roadway safety. The Traffic Impact Report will be reviewed by local agencies and must be approved before development can begin (69).

Relationship of State and MPO

The State of Arizona currently has three MPOs in their three major metropolitan areas: Phoenix, Tucson, and Yuma. The Phoenix (MAG) and Tucson (Pima Association of Governments, PAG) MPOs are designated as TMAs and will have the responsibility for developing a CMS for their jurisdiction. The Arizona DOT will incorporate these CM programs into the state CMS. However, the Yuma MPO is not designated as a TMA; the CMS for that region will be part of the state CMS and not developed by the MPO. The Arizona state CMS network is expected to be developed as an output of the statewide plan. The CMS network (outside of MAG and PAG) will include freeways, the national highway system, and some rural roads maintained by Arizona DOT. As of July 1993, the responsibilities of the CMSs had not been formalized with the MPOs.

The State of Washington has 8 MPOs throughout the state, but only 3 of them are designated as TMAs. The TMAs will have the responsibility for CMS program in their area, and Washington DOT will incorporate the systems into the state CMS. Plans have not yet been finalized, but Washington DOT is planning to work with the remaining five MPOs.

They will be offered the opportunity to include facilities in addition to those on the state highway system. The MPO will have responsibility for data collection on facilities other than state highways while the state DOT will work with the MPO to develop the program. The MPO can have the responsibility for the CMS if they so choose. In effect, other MPOs can have the same role/responsibility for CMS as the TMAs. The state DOT will use the state highway system for the state CMS network.

The New York DOT will retain primary responsibility for CMS, but will work closely with each MPO in developing the CMS. The New York DOT is currently a member of each MPO, and the present working relationship will continue. The CMS is expected to be relevant to each MPO area and meet all New York DOT requirements. The same procedures, methodologies, and definitions are to be used by all MPOs and the New York DOT. Person-hours of delay is expected to be used as the performance measure for congestion. However, a different intensity/threshold of delay will be used for defining unacceptable congestion in each different area or MPO. No further progress in defining the state CMS network has been made, except that the network will be less dense than the National Highway System.

The State of Florida contains 25 MPOs, 11 of which are designated as TMAs. Responsibility for the CMS will be given to all MPOs because there is not much difference between the ones which are TMAs and the ones which are not. State Law requires all cities and counties (459 of them) to set congestion standards on all roads within their jurisdiction, including state highways. The current thinking is that the State will integrate the MPO CMSs into the state CMS. At present, MPOs each use different threshold congestion values which will continue with the development of the CMSs. Florida DOT is working on a formal statement of the responsibilities/relationship of the MPOs, but it is not expected to be completed until late 1993.

The State of New Jersey currently has three MPOs which cover the entire state (however, one has no staff at present and another has a small staff). Therefore, the three MPO CMSs will be the statewide CMS. NJ DOT has employed a consultant to assist MPOs to develop a CMS for their area. As a part of the effort, the consultant will research "how the public views congestion" or "what does the public view to be congested conditions." The NJ DOT sees a strong role for the MPOs and will work with them to coordinate CMS activities and programs. The NJ DOT expects that the CMSs will focus on corridors. CMS is anticipated to be the "umbrella" management system. The Intermodal Management System (IMS) is divided into goods and people, of which the people movement part will be addressed in CMS. The Public Transportation Management System (PTMS) is divided into mobility and facilities/equipment, of which the mobility section will be addressed with CMS.

Agency Comments

Many agencies had specific ideas regarding how congestion management activities should be structured, including what they thought would work and what would not. The

following comments were made by representatives of the various agencies relative to implementing and administering the CMS during the interview process.

- The Bay Area MTC feels that the issue of how to combine air quality requirements and transportation requirements needs to be resolved.

- The Southern California Association of Governments (SCAG) feels that FHWA should be aware that the California law is very weak in tying air quality to congestion levels. Goods movement within urban areas needs to be a part of the CMP as well.

- In regards to growth issues, the SCAG feels the O-D data used are 17 years old and do not account for the increase of women in the work place. Also, urban form has a major impact on VKT (VMT). The CMP must focus on urban form as well as VKT (VMT). Across the region, there is a problem with allocation of trip reductions goals to the various cities. If the CMP does not cover the entire metropolitan area then the CMP is unmanageable.

- The Riverside County TC feels that, in terms of access control guidelines, the use of rigid rules governing arterial streets should be avoided. However, the use of discretionary funds should be linked to the local unit of government adjusting an ordinance on access control to arterial streets. In simple terms, the materials supporting the ordinance should document the value and benefit found in complying with the suggested access control guidelines. The formula funding should not be involved in this part of the program.

- The Riverside County TC also feels that the key to local governments adopting federal guidelines is to give them access to new monies -- if they match a given share of the cost and meet other requirements that may be specified. The lure of new money being available will encourage local governmental units and private sources to obtain the matching funds. The access control suggestions and uniform mitigation fee idea can be suggested as ways to obtain the local funds.

- The Riverside County TC stated that the relationship between congestion and its contribution to air quality is vague at best. Whatever the guidelines for CMS turn out to be, the air quality people should be members of the team and not have approval authority over the plan. The approval authority makes them autocratic and single focus oriented. Under the present system, the air quality people have nothing to loose. Therefore, there is no incentive for them to negotiate openly on the merits of the case under consideration.

- Mr. Blackwelder of Riverside County feels that a distinction needs to be made between a PLAN and a PROGRAM. A PLAN **should not** require an environmental impact analysis. A PROGRAM **should** require complete environmental and traffic

impact analyses. While a PLAN is rather easy to develop, a PROGRAM depends on local elected officials approving each element in their jurisdiction.

- The Federal CMS guidelines must acknowledge the existing traffic congestion, especially on freeways. The Riverside County TC feels that CMS funding should not be used to rebuild the freeway system. If this is allowed, there will be little left for improvement of the arterial network. Also, CMS funding should not be curtailed because of past mistakes. We must start from this point and go forward.

- In implementing a CMP, CALTRANS-11 feels that the FHWA must hold the line on geometric standards, else the cities will drop to lower levels to save money. Arterial street access control is already in place in Southern California; however more detail on signal spacing is needed. Mr. Harvey of CALTRANS-11 feels that a minimum of 0.4 kilometer (1/4 mile) should be enforced.

- The San Diego TMA feels that the new CMS guidelines need to avoid a conflict between the Air Quality Agency and the agency responsible for congestion management such as developed in San Diego. Both the Air Quality District and SANDAG want to be the dominant agency, and the conflict has stopped progress toward cleaner air and congestion management.

- The proposed Air quality guidelines under regulation 1301 (Air Quality District) are unattainable. The San Diego TMA feels that a practical upper bound on ride sharing is 30% of those employed in any given business. This percentage of participation will not achieve the 1301 targets. The targets established must be realistic and attainable. A hard look needs to be taken on fines for non-compliance. It is better to use incentives rather than disincentives. Whatever guidelines come out on CMS, the enforcer of the guidelines must encourage an environment of working together to solve a common problem among all interested persons. SANDAG has done a good job of attempting to do this, but the Air Quality District has not. Their major concerns are:

  a. The complexity of the 1301 regulations,
  b. Cost of the non-compliance and required subsidies to individual businesses,
  c. Auditing and reporting requirements on business, and
  d. The political conflict over who is in charge of the CMS/Air Quality program.

- The San Diego AOG (SANDAG) feels that unanswered questions, concerning land use decisions around interchanges and transit stations, need to be addressed. The present land use decisions allow selected property owners to reap large economic benefits from these decisions. Also, investors attempt to buy land that will be needed for transportation purposes in the near future. There needs to be some way to allow

public agencies to share in these benefits as a means of reducing the cost of construction. The local governments need to be pushed on the access control issue.

- The SANDAG also stated that an important issue in the CMS guidelines is not to place the MPO in the position of policing the cities.

- Currently the CMS guidelines tell the local governmental units how to achieve prescribed goals. SANDAG stressed that if realistic goals are established, then the ingenuity of the local jurisdictions should be able to find a way to meet them.

- The SANDAG pointed out that local streets can be improved rather inexpensively. Two examples were cited to illustrate this point.

  1) On a downtown street two parking curb spaces caused heavy congestion -- removing them eliminated congestion.
  2) In another case, a single right turn lane from a one way street to another one way street caused long queues. Provision of second shared right turn lane eliminated the long queue.

The point is that the system can be improved by relatively simple and low cost improvements if the traffic operations people have the insight to go out and study the problem.

- Mr. Sulzer, Executive Director of SANDAG argues that the 1.5 AVR can be achieved for individual businesses, but he questions the cost effectiveness of the program. However, Mr. Hultgren, Director of Transportation for SANDAG, believes that the 1.5 AVR cannot be achieved. Recently, SANDAG conducted vehicle occupancy surveys which indicated an AVR of 1.19. If transit riders are included in the rate calculation, then the AVR jumps to 1.24. Therefore, it is very important to define how the data are to be collected.

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APPENDIX L

AN EVALUATION OF TRAVEL TIME ESTIMATION METHODOLOGIES

Appendix L is a portion of a paper prepared for a graduate civil engineering course at Texas A&M University. The course, entitled *Advance Surface Transportation Systems*, was offered during the summer of 1993. This portion of the paper is reproduced in this Appendix due to the benefits of using travel time or travel rate as the measure of congestion in a Congestion Management System.

References identified with a large underlined number are general references in this report and are listed beginning on page 29 following Chapter 3. Those identified with small numbers are references within this Appendix and are listed on page 231.

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OVERVIEW

In the fight against traffic congestion, many agencies measure and monitor congestion levels on their freeways and arterial streets. Recent research has determined that travel time or travel rate is the best measure of congestion. Travel time is applicable for many different modes of travel, is able to be projected to predict future conditions, and is easy to measure. This report investigates several different travel time estimation methodologies in order to evaluate their advantages, limitations, accuracy, ease of measurement, and applicability for a variety of different uses.

This appendix is divided into two major sections. The first section describes four existing methods that are currently used to collect travel time data. These methods are the floating car technique, the license plate matching technique, the cellular telephone reporting technique, and the detector systems technique. The second major section identifies emerging technologies which will play a major role in travel time measurement in the near future. These technologies are automatic vehicle identification systems and global positioning systems.

The results indicate that all six travel time estimation methodologies provide an accurate representation of the actual average travel time of the traffic stream. Some methodologies do, however, have advantages over the others for different purposes. For example, for reporting real-time information, the emerging AVI technology will provide the best estimate of travel time assuming enough probe vehicles are in the traffic stream. The AVI technology will improve the estimates made by loop detectors and those reported by cellular telephones because it is measured automatically by the system and does not rely on vehicle length estimates or consistent human reporting. The AVI technology is also useful for measuring and monitoring congestion levels, incident management programs, and fleet tracking for the trucking industry.

However, due to the costs associated with this system, small metropolitan areas will not be able to install the AVI technology. With this in mind, the license plate matching technique proved to be the best method for measuring congestion on an annual basis. This technique provided about 15 times more data than the floating car technique for the same number of man-hours of work. In addition, the license plate technique samples random drivers from the actual traffic stream to produce a more representative sample of the driving population. The license plate matching technique, however, is only recommended for annual congestion measurement, and does not apply to collecting real-time information, incident detection programs, or for fleet tracking.

INTRODUCTION

In the fight to combat congestion, many governmental agencies across the country measure and monitor congestion levels on their freeway system on a regular basis. Congestion levels are measured in many different ways, including Level of Service, delay, speed, volume, and travel time. Due to the passage of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), agencies will soon be required to evaluate more than just one mode of transportation. Agencies will need to measure congestion levels (i.e. mobility) across all modes. In response to this need, NCHRP recently sponsored a study that identified travel time as the preferred measure of congestion (70). Travel time is a measure which can relate to all modes of transportation, including automobiles, transit and ferries, and can be collected and interpreted in a cost effective manner.

Several different methodologies are either currently in use or being developed to measure travel time. These methodologies include: using test vehicles or "floating cars" to physically measure travel times from one location to another; calculating travel times based on information supplied by vehicle detectors; using automatic vehicle identification (AVI); using a license plate matching technique; using global positioning systems; and by drivers who report travel times by cellular telephone after passing a checkpoint.

With several different methods available for measuring travel time, questions have arisen about the accuracy and reliability of each method. The AVI and global positioning methodology are relatively new and not utilized in most parts of the country. The other methodologies have been in use for many years, but are typically time consuming and expensive to use.

Purpose

The purpose of this project is to evaluate the different methodologies in measuring travel times in order to determine their differences, limitations, and ease of measurement. In addition, their applicability in measuring and monitoring congestion and in reporting real-time information will be analyzed. With regards to emerging technology, an investigation into the number of probe vehicles required and the technologies' applicability towards other purposes will be included.

Scope and Study Approach

This paper concentrates on the most common travel time estimation methodologies; namely, floating car measurements, detector measurements, license plate matching, cellular phone reports, AVI technology and GPS technology. Information about the existing methodologies was obtained from agencies that are currently using that methodology to evaluate travel time. These agencies include the Minnesota Department of Transportation, the California Department of Transportation, the Metropolitan Transportation Authority

of Harris County (METRO, Houston), the Washington State Department of Transportation, and the Illinois Department of Transportation.

The evaluation of the emerging technologies was completed by obtaining information from several research projects currently in progress. These include the RTTIS project in Houston, the TRANSCOM project in New Jersey, and the ADVANCE project in Chicago. In some cases, adequate information is still not available for a complete methodology evaluation. Conclusions and recommendations will include the benefits and limitations of each method and the applicability of the travel time estimate for other uses.

EXISTING METHODOLOGIES

Overall travel time, as defined by the Transportation Research Board, is the "total elapsed time of travel, including stops and delays, necessary for a vehicle, or the average for a group of vehicles, to travel from one point to another over a specified route and under existing traffic conditions." (71, p.2) Over the years, different methods have emerged with improvements in technology in an effort to accurately measure travel time. Several methods are currently in use today, including some that have been used for many years, and some that are relatively new. This section investigates the existing methodologies and evaluates their accuracy, usefulness, and ease of measurement.

Floating Car Technique

The floating car technique is a form of the test car technique that is perhaps the oldest travel time estimation methodology. The floating car procedure involves driving a test vehicle through the normal traffic stream and recording the time it takes to travel between certain segments. The driver of the test vehicle tries to "float" in the traffic stream, passing as many vehicles as pass him, in order to obtain a representative travel time for the traffic stream (72).

Other test car techniques which are similar to the floating car technique are the average car technique and the maximum car technique. The average car technique requires the driver of the test car to travel at a speed which he feels is representative of the average travel speed of the traffic stream. The maximum car technique requires the driver to drive the test car at the posted speed limit unless impeded by actual traffic conditions (72).

Minnesota Department of Transportation

The Minnesota Department of Transportation in Minneapolis uses the floating car technique to measure travel time on a roadway segment whenever that segment must be evaluated. One staff member, usually a student technician, travels on the segment within the traffic stream. The operator uses a stop watch to measure time, and reads the time into a tape recorder when passing prearranged checkpoints. In addition, if the vehicle must come to a complete stop, the time that the vehicle was stopped is recorded along with the duration of the stop. Travel time is reported every 3.2-6.4 Km (2 to 4 miles) (73).

The reported travel times for each segment are converted to travel speeds for that segment for evaluation purposes. The travel times are not currently used to provide real-time information to motorists, nor are the travel time measurements considered to contain a high degree of accuracy (73). The measurements are collected for evaluation purposes, not on a continual basis, so continuous real-time information to motorists is not possible.

California Department of Transportation

The floating car technique is also used by District 4 of the California Department of Transportation (CALTRANS-4) located in the San Francisco Bay Area. CALTRANS-4 uses vehicles that are equipped with a computerized program which records the vehicle's speed and current time (74). The vehicles are driven by staff members who travel in the normal travel lanes and record times for each segment, which is 11.3 km (7 miles) or less in length. Data collection only occurs during certain times of the year, such as the spring, for evaluation purposes of freeway segments.

During "full" data collection periods, at least three cars travel on each segment during the peak period (on weekdays only). The effects of minor accidents or other recurring delay is included in the travel time runs. Delays due to major accidents are excluded. A single car is used to check if travel times may have changed since the last full data collection period. If there is evidence that the travel time may have changed, a full data collection effort is completed. The travel time data is not reported in real-time, but it is available for local agencies to use for monitoring congestion levels on an annual basis.

Methodology Evaluation

Travel times measured by the floating car technique are only as accurate as the driver who is recording the data. A variation in travel times exists due to random human error. Other variations exist due to driver judgment as to whether he is "floating" in the traffic stream (i.e. passing the same number of vehicles that pass him).

One advantage of the floating car technique is that no special equipment is required to perform the study. Travel times can be determined using any vehicle, a stop watch, and a tape recorder or note pad.

The major disadvantage is the cost of labor in relation to the amount of data collected. The floating car technique is very labor intensive and is usually limited to a few measurements per day per staff member. Each staff member is limited to two or three travel time runs during the peak period due to time constraints. If the peak period lasts for three hours and each travel time run takes one hour (including time to return to the starting point), only three corridor travel times can be measured by the staff member. Therefore, if the evening peak period is included, only about six travel time runs can be measured along a corridor for an entire day's worth of work for one staff member.

Despite the variation in accuracy and the cost of labor, the floating car technique can provide agencies with an indication of congestion levels on specified corridors on an annual or biannual basis. The floating car technique is not considered to be applicable for use in daily monitoring or real-time traffic reporting, but will provide a relatively inexpensive means of obtaining annual travel time data for measuring and monitoring congestion levels.

License Plate Matching Technique

This travel time estimation methodology requires personnel (or a video camera) to record the time and license plate number of vehicles passing a particular point on the roadway. Another staff member is recording the same data at a different location. The license plate numbers are later matched in order to determine a travel time from one point to the other.

Seattle Study

A recent study in Seattle experimented with both the floating car technique and the license plate matching technique in collecting travel time data on arterial streets (75). Data collection personnel utilized lap top computers to record license plate numbers from vehicles passing several different points on the roadway. The internal clocks on each of the computers were synchronized and the time of entry was recorded for each entered license plate number. Staff members recorded the last three or four numbers of as many license plates as they could. License numbers for sequential data collection points were compared, and travel times were determined for all matches.

At the same time, study personnel were also measuring travel time using the floating car technique. Since the data were collected at the same time, direct comparisons could be made that help to identify the accuracy and reliability of each method. A statistical test was performed to compare the mean travel times obtained from the two methodologies, as shown in Table L-1.

**Table L-1. Comparison of Floating Car and Computerized License Plate
Travel Time Methods**
SOURCE: Reference (6), p. 86.

	Mean Travel Times		Number of Travel Time Runs		t-statistic*
	Floating Car	License Plate	Floating Car	License Plate	
Bel-Red Road Eastbound PM	590	590	5	27	0
148th Avenue Southbound PM	453	487	3	45	-0.44
NE Eighth Eastbound PM	242	264	6	11	-0.40
148th Avenue Southbound AM	247	257	5	38	-0.27

*   The Student's T statistic is used here to compare the mean travel times of the two travel
    time distributions. All t values are within the critical T value at the level of al-
    pha=0.005, and the associated degrees of freedom for each test. This indicates that
    there is no statistical difference between the two travel time methodologies.

The license plate methodology produced results that are statistically the same as the floating car results. The larger number of observations in the license plate survey indicate that the license plate matching results produce a higher level of confidence in the mean travel time estimate than the floating car technique (6). In addition, the floating car technique was estimated to require 1.07 person hours for travel to the site, data collection, and converting the data to useable form. In comparison, the computerized license plate matching technique only required 0.07 person hours per travel time run. Thus, the license plate matching technique produces about 15 times more data than the floating car technique for the same amount of man-hours.

The study also compared estimates based on recording the first 3 numbers verses the first 4 numbers of every license plate. By recording four numbers, false matches are easier to detect because there are fewer of them, but recording four numbers takes longer to collect. However, statistical analysis determined that four-digit entries provided the best combination of ease of data entry and a low level of false matches (6).

Methodology Evaluation

The license plate matching technique provides about 15 times more data than the floating car technique per man hour of labor. In addition, the Seattle study proved that both methods produce identical results. However, the license plate matching technique does provide a larger sample base composed of different drivers and different vehicles operating in actual traffic conditions. The floating car technique typically uses only one or two drivers and one or two vehicles to collect its data over the peak period. On the other hand, the license plate matching technique measures travel times from many different drivers, each driving their own vehicle. This condition provides a more accurate estimation of the mean travel time for all drivers on the system. The license plate matching technique provides a more representative sample of the driving population.

One disadvantage of this technique is that portable computers are usually required. The methodology can be completed with hand written data, but it becomes much more time consuming and labor intensive. Another disadvantage is that the travel times collected are not applicable for reporting real-time information. The reported travel times are only applicable for measuring and monitoring congestion, not for providing information to motorists or transit operators.

Cellular Telephone Reporting Technique

As cellular telephones become more affordable, their existence among drivers increases. This valuable resource tool is a popular method for agencies around the country to obtain real-time traffic information such as incident locations. One such agency began utilizing cellular telephones for obtaining travel time information as part of a prototype traffic information system.

Houston Study

During Phase I of the development of Houston's Real-Time Traffic Information System (RTTIS), 200 drivers were identified through several corporations in the CBD and by newspaper advertisements and word of mouth. These participants were identified to travel one of three corridors daily from the north part of the Houston metropolitan area to the CBD. In return for their participation, the drivers were given a free cellular telephone which they could keep at the end of the study. Each driver agreed to participate for one full year. The study sponsors paid for all connection and monthly access fees for each cellular telephone. Two hundred probe vehicles and drivers were needed in order to provide adequate coverage of the routes during the time the system was operational (76).

The three corridors used in the study (IH-45, US-59, and the Hardy Toll Road) are each approximately 40 kilometers (25 miles) in length and link major residential communities in the suburbs to the CBD. These roadways also provide access to Houston's Intercontinental Airport, located about 21 km (13 miles) north of the CBD. Reporting

locations were identified along each corridor at approximately 5 to 8 km (3 to 5 mile) intervals.

During system operation, drivers called a central communications center as they passed each reporting location. An operator at the center recorded the driver's identification number and location into the computer system. The system recorded the time the number was entered into the computer. Each call lasted less than 10 seconds because all the driver had to say was "driver 143 at point 4." (77) A travel time is automatically determined by the computer by monitoring successive calls by the driver. Travel time data were collected in the inbound direction from 6 to 10 AM and in the outbound direction between 3:30 and 7 PM. During the peak period, travel times were updated for each link segment about every five minutes. Each day, approximately 1500 calls were processed through the central communications center (76).

Methodology Evaluation

Travel times obtained from the cellular phone reporting technique are considered accurate within a minute or two. A variation in travel times was experienced due to the way the drivers reported the data. Times were recorded by the computer when drivers reported their location to the communications center. Therefore, if the line was busy when the driver attempted to report his location, he would have to call again. By the time he connected with the operator, the driver may have been 400-800 meters (1/4 or a 1/2 mile) downstream of the actual reporting point, thereby altering the true travel time.

Other problems with this technique occurred with drivers who would exit the freeway to get gasoline and then return to the freeway and report at the next reporting location. These travel times were obvious outliers to other reported times, so they could be eliminated. In addition, some drivers would forget to call at one location, but remember to call at a following location. Thus, their calculated travel time was for a combination of two segments instead of for one segment.

Despite these problems, the cellular telephone reporting technique does allow more data to be collected than the floating car technique with approximately the same degree of accuracy. In addition, the cellular telephone technique permitted data collection every day of the week without many additional expenses. Major investments were required to install the computer center and provide free cellular telephones. However, the only regular costs beyond installation are computer maintenance, personnel to operate the phone lines, and monthly phone bills. These costs are considerably cheaper per travel time run than with the floating car technique. The cellular telephone technique can provide more data than the floating car technique on a daily basis.

Vehicle Detection Systems Technique

This travel time estimation methodology involves calculating travel times along roadway segments based on information provided by vehicle detectors. Vehicle detectors provide information such as detector occupancy and traffic volume which are then converted to average travel speed for the traffic stream. The speed values are then converted to travel time based on the assumption that the detector data collected at one location represents traffic conditions along the section of roadway to the next detector zone.

Chicago System

An extensive vehicle detection system exists in the Chicago, Illinois area. Approximately 2,000 induction loop detectors along 210 km (130 miles) of the Chicago area freeway system report data 24 hours a day to the Illinois Department of Transportation Traffic Operations Center.

Induction loop detectors are located nearly every 800 meters (1/2 mile) in the center lane of three lane roadways or the left-center lane of four lane roadways. At every five kilometer (3 mile) point, loop detectors are located in every lane. In addition, one loop detector is also located on every entrance and exit ramp throughout the system.

Each detector is connected to a tone transmitter located in a roadside control cabinet which transmits the signal from the roadside to the Traffic Operations Center. A surveillance digital computer in the Traffic Operations Center receives each signal. The computer continuously scans for the status of each mainline loop detector 60 times per second and each ramp detector 12 times per second (78).

Each loop detector operates in the presence mode of operation, which means that the detector unit senses that a vehicle is present on top of the loop and identifies when the vehicle leaves the loop area. By operating the loop detectors in presence mode, the computer is able to determine each loop's occupancy rate. Loop occupancy is the percentage of time that the loop area is occupied by a vehicle. Loop occupancy is the basic form of measurement used at each surveillance point throughout the entire system.

The relationship between loop occupancy, average travel speed, volume, and congested conditions is shown in Figure L-1 (79). A loop occupancy less than 20% indicates free flow conditions on the freeway segment. Between 20 and 30%, conditions on the freeway begin to deteriorate. Speeds are decreasing due to fewer and shorter gaps between vehicles, restrictive flow conditions, and an increased difficulty in changing lanes. These flow conditions are referred to as impending congestion (78). Once loop occupancy passes 30%, conditions are considered to be congested. Speeds continue to deteriorate and throughput volume decreases, as indicated by Figure L-1.

Figure L-1. Generalized Freeway Traffic Flow Characteristics (one lane, at a point)
SOURCE: Reference (79), p. 12.
1 mph = 1.609 km/h
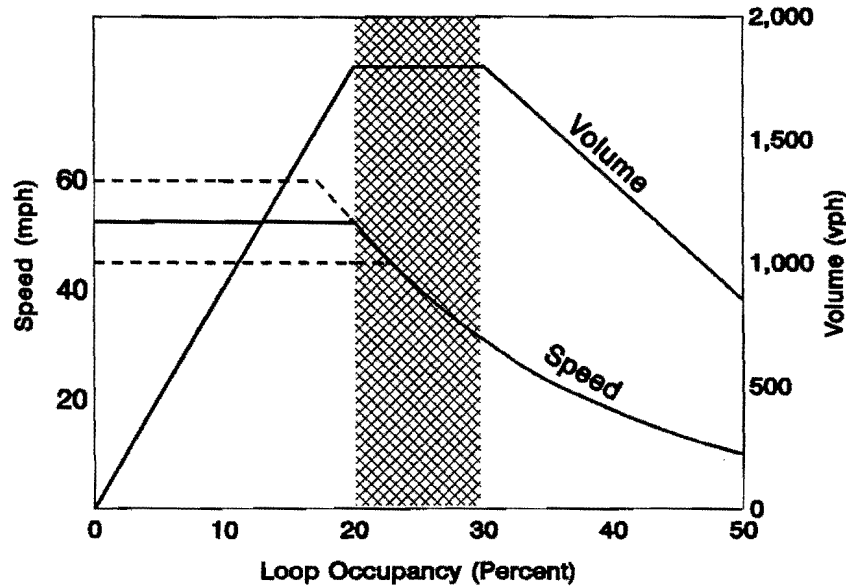
By assuming a standard vehicle length (6.6 m)(21.5 feet) and determining the current lane volume on the freeway, an average travel speed at the location of the detector can be determined. Speeds are determined by the computer program every minute by the following formula.

$$SPEED\ (mph)\ =\ \frac{Volume\ *\ 21.5\ feet}{\dfrac{Loop\ Occupancy}{40.9}}$$

1 mph = 1.609 km/h

Speeds are calculated for each mainline detector using a five-minute data base which is updated every minute. Each loop detector is assumed to represent conditions for the section of roadway from the halfway point to the downstream detector to the halfway point to the next upstream detector. For example, with the detectors spaced at every 800 meters (half mile), each detector is assumed to represent conditions for the 400 meter (quarter mile) segments both upstream and downstream of the detector, for a total distance of 800 meters (half mile), as shown in Figure L-2. From this estimated distance, travel time can be computed based on the estimated speed as follows:

The computed travel times for each 800 m (half mile) segment are calculated every 5 minutes and summed together to determine the total travel time over a given section of

Figure L-2. Schematic of Roadway Segment Represented by Each Loop Detector
1 mile = 1.609 kilometer
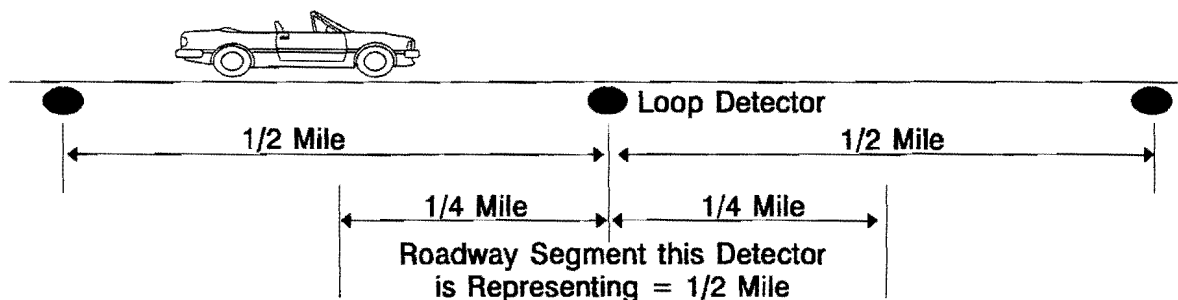
$$Travel\ Time\ (seconds)\ =\ \frac{Distance}{Speed}\ *\ 3600$$

roadway, as shown in Figure L-3. The travel times are summed for predetermined sections of roadway and reported by the central computer at the IDOT traffic control center.

The reported travel time information is used by various radio and television reporters to broadcast real-time travel information to the motoring public. The travel time information is reported for given sections of the freeway system, such as the 26 km (16 mile) section along IH-290 from the Northwest Tollway to Wolf Road (just past the Tri-State Tollway).

Methodology Evaluation

The travel times estimated from loop detectors along the Chicago freeway system permit real-time information to be given to the motoring public. The information permits motorists to make educated decisions about their travel route in order to minimize their travel time.

One disadvantage of the loop detector estimation technique is its reliance on loop detectors for data. Loop detectors require frequent maintenance to maintain their reliability. Studies have shown that loop detectors only provide accurate information when maintained on a regular basis (80). Pavement movements, high volumes of traffic, and construction work all effect loop operations. Operating characteristics of loop detectors are also different with odd-sized vehicles, especially high profile trucks and motorcycles.

However, some of these problems can be overcome. A good routine maintenance program can help keep the loop detectors operating effectively. In addition, the system designed in Chicago is primarily concerned with the characteristics of the entire traffic stream, not with individual vehicles. When determining traffic characteristics, if the loop

detector does not detect an odd-sized vehicle, such as a motorcycle, the travel time estimation will not be greatly affected. The traffic stream characteristics will not change much because the detector did not detect a single vehicle.

Another disadvantage is that the speed estimate is based on an average vehicle length of 6.6 m (21.5 feet). This value represents both high profile trucks and standard automobiles. This standard assumption raises the question of the accuracy of these travel time estimates. Times reported on days with high truck traffic will be high due to the increase in loop occupancy rate caused by the trucks. Similarly, on days with low truck volumes, reported travel times will be lower than actual due to the decrease in loop occupancy rate. The speed estimate could be improved by using speed traps composed of a pair of loop detectors rather than a single loop in the center lane. In this case, speeds are directly determined from the loop detector data and are not based on an average vehicle

Figure L-3. Schematic of Travel Time Estimation for a Roadway Section
1 mile = 1.609 kilometers; 1 mph = 1.609 km/h

	1/2 Mile	1/2 Mile	1/2 Mile
Travel Speed:	30 mph	40 mph	50 mph
Travel Time:	60 sec	45 sec	36 sec
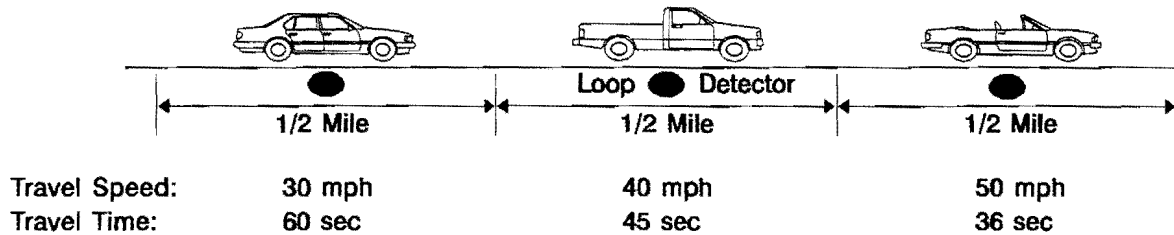
Total Travel Time over 1.5 mile segment = 60 + 45 + 36 = 141 sec = 2 min 21 sec

length.

With regards to travel time estimation, this methodology does have some advantages for reporting real-time information. Measured travel times represent actual roadway conditions since they are based on real-time information. By using the floating car technique, reported travel times are for the segment of roadway just traveled on. This measured travel time will not help the driver who is just starting his trip. For example, if the floating car technique measures a travel time of 50 minutes on a 40 km (25 mile) segment, the reported time of 50 minutes does not apply to a driver just beginning the 40 km (25 mile) segment. Traffic conditions at the beginning of the segment have changed since the floating car technique was started. This driver's travel time will either be better or worse than what was measured by the floating car technique, depending on the time of the peak hour. However, the travel times estimated with loop detectors are estimated over small segments and update conditions every five minutes.

EMERGING TECHNOLOGIES

Over the years, different methods have emerged with improvements in technology in an effort to accurately measure travel time. With the beginning of the IVHS era a few years ago, a few new technologies have emerged on the scene; namely, automatic vehicle identification (AVI) and global positioning systems (GPS). Several research projects in different areas of the country have recently begun utilizing this promising technology to measure travel time as part of real-time motorist information systems. This section investigates these emerging technologies and evaluates their accuracy, usefulness, and ease of measuring travel time. In addition, the required number of probe vehicles will be discussed along with applicability of AVI to other motorist or industry services.

Automatic Vehicle Identification

Automatic vehicle identification (AVI) is a definite improvement in technology over the current travel time estimation methodologies. The technique involves placing a device in a vehicle which transmits the vehicle's identification number. Receiving units placed along the roadway receive the signal when the vehicles pass by. The receiving unit then transmits the signal to a central computer or communications center. By monitoring several receiving units, the computer can determine a travel time by noting the time it takes a vehicle to pass two sequential receivers. This technology has the advantage of being able to determine travel times continuously, assuming many vehicles in the traffic stream are equipped with the transmitting device. The methodology is still in the developing stage in different parts of the country so an evaluation of actual travel time data is not possible. However, a review of the proposed methodology will follow, including a look at other applications of AVI.

RTTIS Project

During Phase II of Houston's RTTIS project, AVI technology will replace the cellular telephone reporting technique previously discussed. Beginning in the Fall of 1993, 5 corridors of the Houston freeway system will be equipped with AVI readers spaced every 5 to 8 km (3 to 5 miles). This is an expansion of the previous system utilizing cellular telephones. Approximately 1,000 probe vehicles equipped with AVI transmitters will travel the corridors during the peak period to/from the CBD/suburbs. Drivers of probe vehicles will again be selected based on their work location, their home location, and their work hours in order to evenly spread the probe vehicles throughout the peak period (76).

The AVI readers will be installed as close as possible to the reporting locations used during the cellular telephone test. The readers used in this study will be placed above the travel lane. In order to save installation costs, they will be placed on existing structures such as overhead sign supports and bridges. In some cases, these structures do not exist at the existing cellular telephone reporting locations (77).

Travel time information will be determined at the central communications center by a computer system. At the present time, the primary user of the information will be the Motorist Assistance Patrols to try and identify incident locations. Eventually, the information will be used by other local agencies (such as METRO for use in bus routing) and commercial vehicle companies (such as Federal Express).

TRANSCOM Project

The TRANSCOM Electronic Toll and Traffic Management (ETTM) IVHS Operational Field Test is studying the feasibility of an incident detection system for the New Jersey to Staten Island corridor. The measurement of travel time using the AVI technology is the proposed methodology for detecting incidents. The project feasibility study was completed in February 1993 and implementation is expected before the beginning of 1994 (81).

The ETTM (same as AVI) tags will be placed in selected vehicles traveling on the study corridors in northeastern New Jersey. The system is scheduled to be installed in three phases. Reader units placed along the roadway will identify tagged vehicles and transmit vehicle identification, reader arrival time, current reader ID lane number, and reader status information to the central computer. The computer will calculate vehicle travel times based on two sequential readers that have identified the same vehicle.

For incident detection purposes, the measured travel times will be converted to average travel speed. The incident detection algorithm uses the speed distribution for each location and individual time periods to project the vehicle's path to the next ETTM detector. The probability of the vehicle's arrival at the next detector is continuously calculated so the probability of an incident can be determined (82). The only travel time data which will be stored by the computer are those which are beyond the expected arrival time (i.e. those which indicate an incident). Travel times which are within the expected range will be discarded.

If the false alarm rate is kept below two percent, incident detection time can be held below five minutes. Therefore, in order to accomplish this task, readers must be placed less than or equal to 2.4 km (1.5 miles) apart. The 2.4 km (1.5 mile) spacing will permit fewer readers than a 0.8 or 1.6 Km (0.5 or 1.0 mile) spacing and keep costs to a minimum. However, in some cases due to topography or roadway geometries, readers may need to be placed closer together. Closer spacing of readers will reduce the incident detection false alarm rate, but it will also increase capital costs.

Methodology Evaluation

The emerging AVI technology appears to be a vast improvement over traditional travel time estimation methodologies. The AVI system under construction in Houston will eliminate the majority of the problems discovered with the cellular phone reporting technique. Consistent reporting of vehicle location and time of day by the AVI readers will eliminate the human errors in reporting and recording the vehicle's location. The system is also completely automated, so operating costs will be lower with the elimination of the telephone operators.

In theory, the AVI readers should be capable of reporting real-time traffic information assuming enough probe vehicles are in the traffic stream. Travel times for each segment can be updated frequently with an adequate number of probe vehicles detected. The AVI real-time estimation is an improvement over the current loop detector estimation procedures. The AVI technology can measure travel times over small segments of roadway and then sum the data to estimate a travel time over the entire section. Similarly, the loop detector systems estimate travel time over 800 m (1/2 mile) segments and sum the data to estimate travel times over the entire section. The major improvement with the AVI technology is that travel times are actually measured by probe vehicles traveling in the traffic stream. Loop detector systems estimate travel times based on loop occupancy, lane volume, and an assumed vehicle length. Problems previously identified with these estimations are eliminated by using the AVI technology.

In addition, the AVI technology provides accurate data for use in measuring and monitoring congestion levels along both freeways and arterial streets. The technology provides daily travel time measurements for monitoring overall travel conditions on the roadway, including buses, other transit vehicles, and the use of HOV lanes. The data collected will eliminate the need for annual or biannual congestion measurements using the floating car or license plate matching techniques.

Global Positioning Systems

Global positioning systems (GPS) involve using a satellite system to continuously track a vehicle's location. Vehicles are equipped with a receiving device and a screen which displays a map of the area and the vehicles exact location. Most GPS systems can pinpoint the accuracy of a vehicle to around 15 to 30 m (50 to 100 feet) (83). This technology may have the advantage of being able to determine travel times continuously assuming many vehicles in the traffic stream are equipped with the receiving device. The methodology is still in the developing stage in different parts of the country so an evaluation of actual travel time data is not possible. However, a review of the proposed methodology will follow including an investigation into the proposed number of probe vehicles needed to operate effectively.

ADVANCE Project

The Advanced Driver and Vehicle Advisory Navigation Concept (ADVANCE) is a joint public-private venture in the northeastern Illinois suburbs near Chicago. ADVANCE will provide real-time traffic information to drivers to help reduce congestion and travel time. Each vehicle will be equipped with a navigation and route guidance system consisting of a video screen, a microcomputer, a data communications radio, and a global positioning satellite receiver. The satellite receiver will help determine the vehicle's exact location in order for proper navigational instructions to be given.

Current traffic information will be gathered from and transmitted to the vehicles over a dedicated frequency communications system. The vehicles themselves will be functioning as traffic probes, and will calculate their own travel times with the on-board computer. Any travel time which is computed to be abnormal (i.e. longer than expected) is reported back to the Traffic Information Center. This information, along with information from police reports and other sources, will allow the computer system to determine the best possible route to suggest to the driver (84). The transfer of information in ADVANCE is illustrated in Figure L-4.

Figure L-4. The ADVANCE Data Transmission Concept
SOURCE: Reference (18)
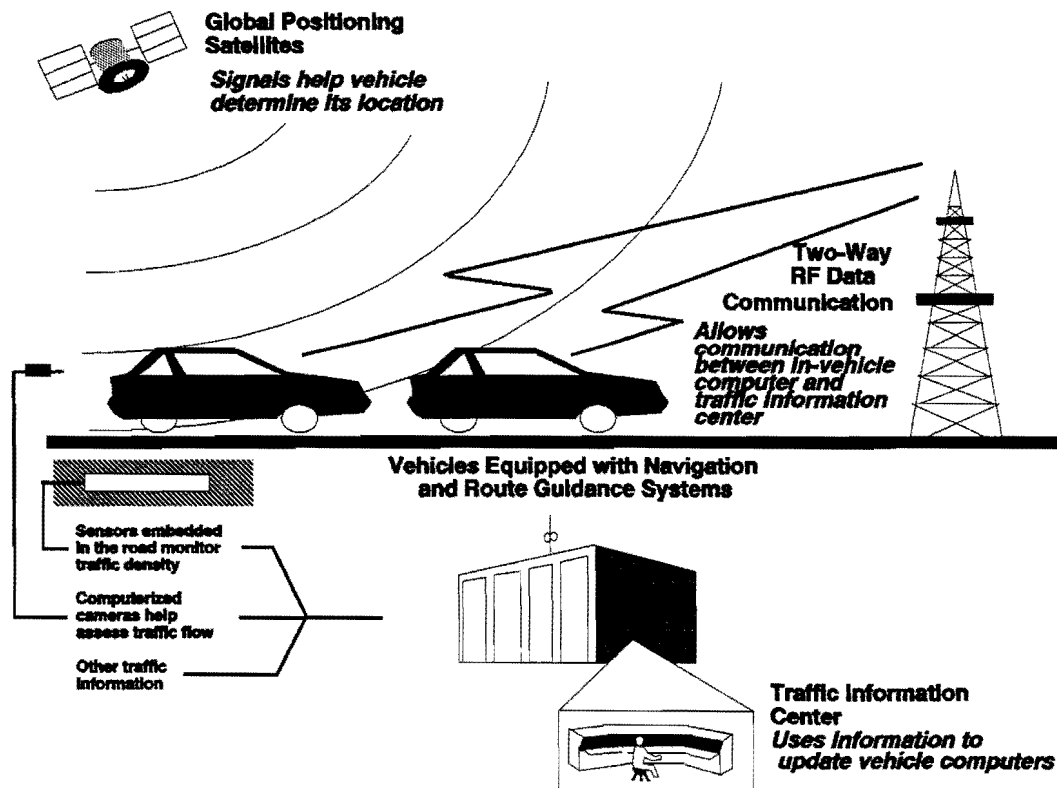
Probe Vehicle Sample Size

For the ADVANCE project, researchers estimate that 5,000 probe vehicles will be required for enough data to be available for the system to operate effectively. The probe estimate was developed by solving a static, user-optimal route choice model for the road network under consideration during the morning peak period. The total number of trips expected during the peak hour is about 185,000. Thus, the 5,000 probe vehicles would comprise about 2.7% of the traffic stream. During a 20 minute time period, these probe vehicles will traverse about 75% of arterial links in the network. It is anticipated that this percentage will provide sufficient information to evaluate current traffic conditions (85). The proportion of links traversed based on the number of probe vehicles is shown in Figure L-5.

At the time of this analysis, the network comprised 51,780 ha (200 square miles), and 4,000 probe vehicles were recommended for use in the project. Since the time the report was published, the network has been expanded to cover 51,780 ha (250 square miles) and the number of required probe vehicles has been increased to 5,000.

In addition, the information transfer process between the probe vehicles and the traffic information center was designed based on the number of probe vehicle reports expected during a short time period. Assuming a worst case scenario and each probe vehicle reported a travel time following a link traversal (each intersection), 3,170 probe reports would be transmitted during a 10 minute period. Therefore, the system had to be designed to accommodate at least 317 probe reports every minute (86). The amount of data that could be transferred during a given time period was a major factor in selecting the probe vehicle sample size.

Due to this process of information transfer from the probe vehicles to the traffic information center, travel times are only reported by the vehicles if they deviate from normal conditions. Therefore, it is possible, although highly unlikely, that all 5,000 probes are travelling within the network and nothing is being reported to the traffic information center. More information regarding the estimation of the required number of probes will be released by the project staff in the near future.

Methodology Evaluation

In theory, GPS technology should be capable of reporting real-time traffic information assuming enough probe vehicles are in the traffic stream. Travel times for different segments of the network are calculated continuously by probe vehicles travelling on that segment. However, only travel times which are unusually long are reported to the traffic information center due to the restrictions on the amount of data that can be transmitted between the vehicles and the traffic information center. This limitation decreases this methodologies applicability for collecting historical travel time data for monitoring congestion. The only data that will be obtained is data for congested conditions.

Figure L-5. Link Coverage of North Shore Network - All Arterial Links
SOURCE: Reference (85), p. 20.
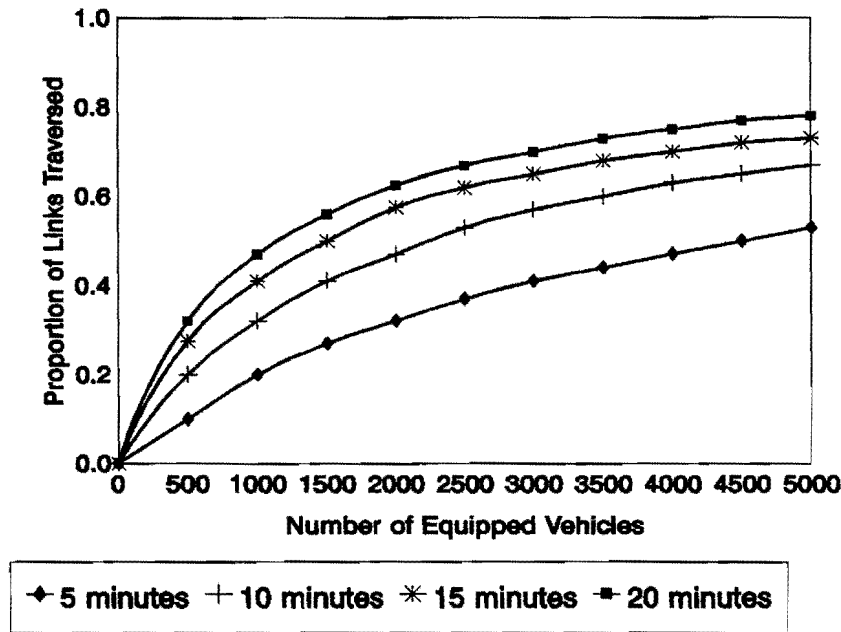
The major improvement made by using GPS technology is that travel times are actually measured by probe vehicles traveling in the traffic stream. Loop detector systems estimate travel times based on loop occupancy, lane volume, and an assumed vehicle length. Problems previously identified with these estimations are eliminated by using the GPS technology since travel times are measured and not estimated.

In addition, problems exist with the willingness of the public to install the navigation, route guidance, and computer systems in their vehicles. The travel times calculated by GPS technology will not exist without properly equipped probe vehicles travelling in the traffic stream. Despite these problems, the GPS technology appears to be a promising technology that will provide many benefits, such as route guidance and navigation, to motorists in the near future.

CONCLUSIONS

Each of the evaluated travel time methodologies has certain advantages and disadvantages for different applications and for overall effectiveness and reliability. Table L-2 identifies general information regarding costs, labor, equipment and proven reliability. Table L-3 identifies the applicability of the travel time estimate for different uses, including congestion measurement and monitoring activities, incident detection, and for providing real-time information. Of the six travel time estimation methodologies evaluated, only three (the floating car technique, license plate matching technique, and detection systems technique) have been completely field tested. The cellular telephone reporting technique is still under evaluation and the AVI and GPS systems are just beginning to be implemented. However, from the available information, several comparisons could be made between the estimation techniques.

The accuracy of the travel time estimate is one important factor to consider. The floating car technique and license plate matching technique estimates were proven to be reliable and identical estimations of the average travel time along a segment. The detector systems methodology also provides a good travel time estimate providing that the actual average length of vehicles is near the 6.6 m (21.5 feet) used in the estimation procedure. The cellular phone technique provides an estimate which is not as accurate, primarily due to the variability in driver reporting times. The two emerging technologies are expected to improve the travel time estimate, due to the automated characteristics, but the techniques have not been completely implemented yet.

Table L-2. Comparison of Travel Time Estimation Procedures

	Floating Car Method	License Plate Matching	Cellular Phone Reports	Traffic Detector Data	AVI Tags	GPS System
Methodology Completely Field Proven	Yes	Yes	Somewhat	Yes	No	No
Accuracy of Estimate	Good	Good	Fair	Good	Great	Great
Methodology Labor Intensive	Yes	Yes	Somewhat	No	No	No
Special Equipment Required	No	Somewhat	Yes	Yes	Yes	Yes
Comparable Cost of Initiation	Low	Low	Med	High	High	High
Operating Cost/Travel Time Run	Med	Low	Med	Low	Low	Low
Cost of Routine Maintenance	None	None	Med	High	?	?

Table L-3. Applicability of Travel Times Computed from Various Methodologies

Computed Travel Time Applicable for	Floating Car Method	License Plate Matching	Cellular Phone Reports	Traffic Detector Data	AVI Tags	GPS System
Annual Congestion Measurement	Y	Y	Y	Y	Y	Y
Daily Congestion Monitoring	P	P	Y	Y	Y	Y
Providing Real-Time Information	N	N	P	Y	Y	Y
Daily Incident Detection	N	N	Y	Y	Y	Y
Evaluating Incident Detection Effectiveness	P	P	Y	Y	Y	Y

Y = Yes   P = Possible but not recommended   N = No

The floating car and license plate matching techniques are the most labor intensive compared to the other four methods. The cellular phone method requires some degree of labor to operate the phone system. The other methods rely on electronics and computer systems to automatically collect and record data, thereby eliminating the reliance on manual labor.

An advantage of the floating car technique is that no special equipment is required for implementation. Travel times can be determined with any vehicle and a stopwatch. The license plate matching technique works best when portable computers are used to collect data, but it is possible (but not recommended) to utilize this technique without them. The remaining methods all require specialized equipment, including such items as cellular phones, computer systems, vehicle detectors, and navigation systems.

In respect to investment, operating, and maintenance costs, specific data were not available for each method as to their exact costs. However, general cost comparisons could be made based on each technique's procedures and operating and maintenance requirements. On an annual basis, the floating car and license plate matching techniques' costs are low compared to the other methods. The AVI, GPS, and detector system methodologies require a large investment for equipment installation and equipment maintenance. The cellular phone reporting technique is probably somewhere in between. The only costs associated with installation of this technique are the purchases of many cellular telephones, the installation of a computer system, and the hiring of a phone operator.

Cost per travel time run is low for all methodologies, with the exception of the floating car technique. For each man-hour of labor with the floating car technique, you get only one completed travel time run. However, for the license plate matching technique, about 15 travel time runs are recorded for each man-hour of labor. The cellular telephone reports and detector systems travel time estimations are assumed to be comparable, since many travel time runs are reported every hour by motorists or the loop detector system. Even though the AVI and GPS systems have not been field tested, it is assumed that their performance per man-hour will be similar to the detector systems technique.

Maintenance costs for the detection systems technique will be the highest due to the problems associated with maintaining loop detectors. The floating car and license plate matching techniques do not require routine maintenance since they are not used on a daily basis. The cellular phone reporting technique requires routine costs for monthly phone usage and for operating the traffic control center, but these costs are not as high as those for maintaining nearly 2,000 loop detectors. Unfortunately, it is currently unknown as to the amount of maintenance that will be required for the AVI and GPS systems since they are still in the developing stages.

As indicated in Table L-3, the travel times determined from the various methodologies have a wide variety of applications, from congestion measurement to incident detection. All six methodologies are applicable for measuring congestion on an annual basis for use in a congestion management system. However, the floating car method and the license plate matching technique are not recommended for use for daily congestion measurement. The costs associated with using these techniques daily far outweigh the benefits. The other four methodologies would provide daily congestion monitoring information more effectively.

The traffic detector systems, AVI systems, and GPS systems are the only three travel time estimation techniques recommended for providing real-time information to motorists. The other three methodologies are not accurate enough for real-time reporting, and typically are not reported soon enough to be of use to a motorist just beginning his trip.

For incident detection, the reported travel times for the last four methodologies are applicable for both detecting incidents and evaluating incident detection response times. In order for the floating car method and the license plate matching technique to be effective for incident detection, they would have to be done on a continual basis, which makes their use impractical. Incident detection strategies require real-time data about traffic conditions, which the floating car technique and the license plate matching technique are not able to provide. If the final four methodologies are operating effectively, they can be used for evaluating the effectiveness of incident detection procedures. Travel times measured on days before and after the implementation of an incident management program can help to quantify the effect the program has had on traffic conditions.

RECOMMENDATIONS

For measuring and monitoring congestion, providing real-time information, detecting incidents, and assisting the trucking industry, the travel time estimation technique using the automatic vehicle identification technology is preferred over all other methods. The AVI technology accurately measures travel time, and, assuming enough equipped vehicles are in the traffic stream, the data can be reported in real-time. The GPS technology also accomplishes these tasks, but evaluations from several different field tests have not yet been released. Problems are also apparent with the GPS technology in data transfer from individual vehicles to the communications center. If every vehicle using a roadway will someday be equipped with a GPS system, the data transfer portions of the system must be improved.

The other methodologies, however, are not without merit. For annual congestion measurements, small metropolitan areas can obtain accurate travel time estimates using the license plate matching technique. This method is preferred over the others because of the amount of accurate data that can be collected per man-hour of labor. In small towns, personnel and labor requirements are very important due to the limited transportation staff available. The other methodologies are either too costly or do not provide as much accurate data as the license plate matching technique. Small metropolitan areas are typically not equipped with sophisticated and expensive detection systems to use for travel time estimation.

For cities with established traffic detection systems, the detector systems technique will provide accurate travel time estimates for congestion monitoring and incident detection purposes. However, this methodology is not recommended for cities implementing a new system. The AVI system is preferred because of the degree of accuracy of the travel time estimate.

The cellular telephone matching technique can be used in areas that cannot afford elaborate detection systems if enough volunteers are available who own cellular telephones. The travel times reported are accurate within about a minute, on average, and do provide an adequate picture of the status of congestion or the effectiveness of an incident management program.

Thus, the automatic vehicle identification technique is the preferred travel time estimation methodology for those agencies which want to reap all of the benefits of measuring travel time, such as congestion monitoring, real-time traffic information, incident detection, and fleet tracking. For agencies only interested in annual congestion measurement, the license plate matching technique is preferred over the other methodologies based on its accuracy, cost per travel time run, and ease of implementation.

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