CONGESTION MITIGATION RESOURCES AND STRATEGIES FOR ARIZONA'S STATE HIGHWAY SYSTEM

Final Report 542

Volume I - Research Goals, Activities and Conclusions

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16. Abstract –

Growing traffic congestion is one of the most significant problems for the transportation system in Arizona, and the nation. Our propensity for single-occupant vehicles has produced not only the well documented metropolitan congestion but has become a universal problem, spreading to smaller urban and rural locations. Congestion affects the movement of people, the flow of goods to market, quality of life, energy consumption and the environment, including regional air quality. It impacts the ability to compete in the modern marketplace. As Arizona's population grows, congestion on the state's urban freeways and rural highways will only worsen. A challenge for the Arizona Department of Transportation (ADOT) will be to use a variety of practical, relevant congestion mitigation options in appropriate, collaborative and innovative ways to address current and future congestion problems.

To meet this challenge, ADOT has undertaken the development of a comprehensive Congestion Mitigation Methodology for the implementation of a consistent and sustained approach to assess and manage the growing congestion problem on all elements of the state highway system. This effort has resulted in the development of practical strategies to solve Arizona's mobility and congestion problems. A significant step in the development of the Congestion Mitigation Methodology was building a consensus among traffic management stakeholders on effective definitions for congestion and for congestion management. Input on the definitions and state of the practice in congestion mitigation came from a national survey of Metropolitan Planning Organizations and state Departments of Transportation and from a state-wide conference on congestion mitigation. The research project has produced recommendations for systematically quantifying congestion on Arizona's highways using a state-specific congestion index, and has also produced a database of available congestion mitigation strategies in Microsoft Access. The Arizona congestion index, mitigation strategies database, and a set of sound, practical project programming procedures are the primary elements of the emerging ADOT congestion mitigation toolset.

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
		ILLUMINATION		
fc	foot candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE AND PRESSURE OR STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	Square millimeters	0.0016	square inches	in^2
m^2	Square meters	10.764	square feet	ft^2
m^2	Square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	Cubic meters	35.315	cubic feet	ft^3
m^3	Cubic meters	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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ACRONYMS

AAA	American Automobile Association
AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
ADOT	Arizona Department of Transportation
ATMS	Advanced Traffic Management Systems
ATRC	Arizona Transportation Research Center
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
BRT	Bus Rapid Transit
BWR	Bucher, Willis & Ratliff Corporation
CAAG	Central Arizona Association of Governments
CMS	Congestion Management System
CVO	Commercial Vehicle Operations
DEQ	Department of Environmental Quality
DMS	Dynamic Message Signs
DPS	Department of Public Safety
FHWA	Federal Highway Administration
FMS	Freeway Management System
HAR	Highway Advisory Radio
HCM	Highway Capacity Manual
HCRS	Highway Closure and Restriction System
HOV	High Occupancy Vehicle
HOT	High Occupancy Toll
HPMS	Highway Performance Monitoring System
ISTEA	Intermodal Surface Transportation Efficiency Act
ITS	Intelligent Transportation System
LOD	Level of Development
LOS	Level of Service
MAG	Maricopa Association of Governments
MARC	Mid-America Regional Council
MCDOT	Maricopa County Department of Transportation
MOE	Measures Of Effectiveness
MPO	Metropolitan Planning Organization
NAU	Northern Arizona University
NCHRP	National Cooperative Highway Research Program
PAG	Pima Association of Governments
PMT	Person Miles Traveled
ROW	Right-of-Way
RPTA	Regional Public Transportation Authority
RWIS	Road Weather Information Systems
SOV	Single Occupant Vehicle
TAC	Technical Advisory Committee
TDM	Travel Demand Management
TPD	Transportation Planning Division
TSM	Transportation System Management
TTI	Texas Transportation Institute
V/C	Volume-to-Capacity Ratio
VMS	Variable Message Signs
VMT	Vehicle Miles Traveled

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ADOT Transportation Technology Group's Tim Wolfe served as champion and ADOT ATRC's Steve Owen served as the ADOT project manager for the **Congestion Mitigation Resources and Strategies for Arizona's State Highway System** research project. A Technical Advisory Committee (TAC), listed below, guided the consultant team in the project.

Technical Advisory Committee

(TAC alternates in parentheses)

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EXECUTIVE SUMMARY

Growing traffic congestion is one of the most significant problems for the transportation system in Arizona, and in the nation. Our propensity for single-occupant vehicles has produced not only well-documented metropolitan congestion but has become a universal problem, spreading to smaller urban and rural locations. Congestion affects the movement of people, and the flow of goods to market. It affects quality of life, energy consumption and the environment, including regional air quality. It impacts the ability to compete in the modern marketplace. As Arizona's population grows, congestion on the state's urban freeways and rural highways will only worsen.

A critical challenge for the Arizona Department of Transportation (ADOT) is to use a variety of practical, relevant congestion mitigation options in appropriate, collaborative and innovative ways to address current and future congestion problems. To meet this challenge, ADOT has undertaken the development of a comprehensive Congestion Mitigation Methodology for the implementation of a consistent and sustained approach to assess and manage the growing congestion problem on all elements of the state highway system. In order to develop a comprehensive methodology, on a request from the ADOT Core Team, ADOT's Arizona Transportation Research Center (ATRC) initiated the **Congestion Mitigation Resources and Strategies for Arizona's State Highway System** research project. The main goal of this research was to develop a tool chest of practical strategies to help solve Arizona's urban and rural mobility and congestion problems as they arise in the long-term future. Bucher, Willis & Ratliff Corporation, in association with local and regional consultants, was selected to undertake the research project with oversight from the ATRC and a Technical Advisory Committee (TAC) made up of key ADOT staff, as well as representatives from the major urbanized counties, the regional planning organizations, and the Federal Highway Administration.

The primary objective of this research effort was to identify a variety of practical planning tools and mitigation strategies that can be used to help anticipate, detect and solve congestion problems in Arizona's 6,200-mile State Highway System. A key factor in the long-term success of this statewide effort is building consensus among Arizona's transportation stakeholders on the issue of congestion including its definition and methods of measurement. At the conceptual stage of the project, the TAC recognized the need to carry out the research in phases. The scope was developed as a comprehensive three-phase work plan:

- Phase I of the research effort was to assess the current congestion mitigation practices in the state of Arizona. The identification stage involved a thorough baseline study of Arizona's current state, regional and local congestion mitigation practices, policies, measurements, and systems, as well as any ongoing congestion mitigation planning efforts. Two tasks were specifically designed to achieve the objectives of this phase: (1) Conduct an agency survey to review current agency practices; and (2) Review the current State Transportation Plan and related studies within the State of Arizona.

- Phase II of the research effort was focused on congestion itself. Two major objectives of this phase were to arrive at an acceptable definition of congestion on Arizona's highways and to analyze the methods of measuring congestion and its impacts. Three tasks were specifically designed to achieve the objectives of this phase: (1) Comprehensive review of literature; (2) Survey of agencies, transportation professionals and researchers on a nationwide basis; and (3) Regional conference and workshop.

- Phase III of the research effort was focused on the development of a toolbox of congestion mitigation resources and strategies most suitable for implementation in Arizona. The toolbox was to include a measure of congestion known as the "Congestion Index" and a database of congestion mitigation techniques. Key to this phase was the synthesis of the information gathered through Phases I and II.

Under Phase I, the findings of the Arizona agencies surveyed provided a good background and resource in the development of the congestion mitigation strategies toolbox. Review of the State Transportation Plan and related studies provided a useful guide and input in the selection of appropriate congestion mitigation strategies.

Under Phase II, the comprehensive literature review yielded: (1) criteria for performance measurement; (2) techniques to collect or estimate congestion data; (3) strategies to mitigate and/or manage congestion; and (4) evaluation procedures. The nationwide survey indicates that Arizona is in a similar situation to its partner states throughout the country in striving to manage congestion, incorporate performance based measures, and attempting to tie congestion monitoring to planning and programming. The regional conference and workshop yielded considerable insight with emphasis on Arizona-specific issues.

Under Phase III, based on the work performed in Phases I and II, a toolbox consisting of a congestion index and a mitigation strategies database was developed.

This research project has resulted in the development of practical strategies to solve Arizona's mobility and congestion problems. A significant step in the development of the Congestion Mitigation Methodology was building a consensus among traffic management stakeholders on effective definitions for congestion and for congestion management. Input on the definitions and state of the practice in congestion mitigation came from a national survey of Metropolitan Planning Organizations and state Departments of Transportation, and from a state-wide conference on congestion mitigation.

The research project has produced recommendations for systematically quantifying congestion on Arizona's highways using a state-specific congestion index, and has also produced a database of available congestion mitigation strategies in Microsoft Access. The Arizona congestion index, mitigation strategies database, and a set of sound, practical project programming procedures are the primary elements of the emerging ADOT congestion mitigation toolset.

1. INTRODUCTION

1.1 PROJECT BACKGROUND

Population growth in Arizona taxes the state's transportation facilities at a rate exceeding available capacity, causing continuously increasing congestion, particularly in Maricopa and Pima counties but also in and around Flagstaff, Yuma and along certain rural portions of interstate corridors and other state highways. Examples of rural congestion include I-10 between Phoenix and Tucson, I-17 north of Phoenix, and parts of emerging urban corridors such as State Route (SR) 179 near Sedona, SR 69 in Yavapai County, and SR 260 near Payson. Congestion affects the movement of people, the flow of goods to market, and the regional air quality, and it impacts the ability to compete in the modern marketplace. As congestion on the State's rural and urban highways is expected to worsen with time, a strategic planning approach must be implemented to develop tools that will help the Arizona Department of Transportation (ADOT) and other public agencies in measuring, predicting, and remedying those congestion problems.

The challenge for ADOT will be to use a variety of practical, relevant congestion mitigation options in appropriate, collaborative and innovative ways. The systematic linking of various mobility solutions may not only reduce the congestion problem but also enhance the environment.

The development of a statewide ADOT Congestion Mitigation Methodology would permit the implementation of a sustainable approach to planning for and managing the growing congestion problem on all elements of the state highway system.

Acting on a request from the ADOT Core Team, ADOT's Arizona Transportation Research Center (ATRC) initiated the **Congestion Mitigation Resources and Strategies for Arizona's State Highway System** research project. The main goal of this research was to develop a tool chest of practical strategies to help solve Arizona's urban and rural mobility and congestion problems as they arise in the long-term future. Bucher, Willis & Ratliff Corporation, in association with local and regional consultants, was selected to undertake the research project with oversight from the ATRC and a Technical Advisory Committee (TAC) made up of key ADOT staff, as well as representatives from the major urbanized counties, the regional planning organizations, and the Federal Highway Administration. The project was kicked off in January 2002.

1.2 PROJECT REQUIREMENTS

The primary objective of this research effort was to identify a variety of practical planning tools and mitigation strategies that can be used to help anticipate, detect and solve congestion problems in Arizona's 6,200-mile State Highway System. This mix of congestion mitigation strategies will provide a sound approach to both urban and rural mobility issues in Arizona. The development of these strategies should consider the variety of technology resources that are now or will soon become available.

A key factor in the long-term success of this statewide effort was building consensus among Arizona's transportation stakeholders on the issue of congestion including its definition and methods of measurement and resolution. To that end, this research should strive to answer the following fundamental questions:

- How is congestion defined and measured in Arizona today?
- Where does congestion occur in Arizona and how big of a problem is it?
- Where can congestion be expected to occur in the future?
- What is the threshold of transportation system breakdown?
- What are the costs of congestion?
- What are the urban and rural congestion issues?
- What solutions exist or will soon become available?
- What are appropriate, valid mitigation performance measures?
- Is congestion inevitable?
- Can we "build our way out" of congestion?

Resolving these fundamental issues requires a baseline assessment of congestion and congestion management in the state, as well as the practical experience elsewhere in the United States to help synthesize an appropriate mix of strategies for Arizona.

A strategic approach to the problem should involve a mix of conventional and advanced technologies and concepts, and a plan to develop partnerships to ensure connectivity between these mobility alternatives. This plan should inform, encourage and enable both the public and private sector to look at mobility alternatives in new and different ways.

1.3 RESEARCH SCOPE

At the conceptual stage of the project, the TAC recognized the need to carry out the research in phases. Figure 1 outlines the comprehensive three-phase work plan.

Phase I of the research effort was an assessment of the current congestion mitigation practices in the state of Arizona. The identification stage involved a thorough baseline study of Arizona's current state, regional and local congestion mitigation practices, policies, measurements, and systems, as well as any ongoing congestion mitigation planning efforts. Two tasks were specifically designed to achieve the objectives of this research phase. Task One was to conduct an agency survey to review current agency practices. Through the TAC's guidance, representatives from fifteen municipal, regional, and state agencies were requested to respond to the survey. Task Two was to review the current State Transportation Plan and related studies within the state to document existing definitions, mitigation applications, and measurements of congestion.

Phase II of the research effort was focused on congestion itself. The objectives of this phase were to arrive at an acceptable definition of congestion on Arizona's highways and to analyze the methods of measuring congestion and its impacts. The definition stage involved a comprehensive review of congestion mitigation and management in other parts of the country. Three important tasks were directed to achieve the objectives of Phase II. Task One was to carry out a comprehensive review of current literature on congestion-reduction options, communications and advanced vehicle technology. Task Two was to undertake interviews of practicing transportation professionals and researchers. Task Three was to culminate the efforts in Phase I and II in a regional conference and workshop.

Phase III of the research effort was focused on the development of a tool chest or toolbox of congestion mitigation resources and strategies most suitable for implementation in Arizona. Key to this phase is the synthesis of the information gathered through Phases I and II.

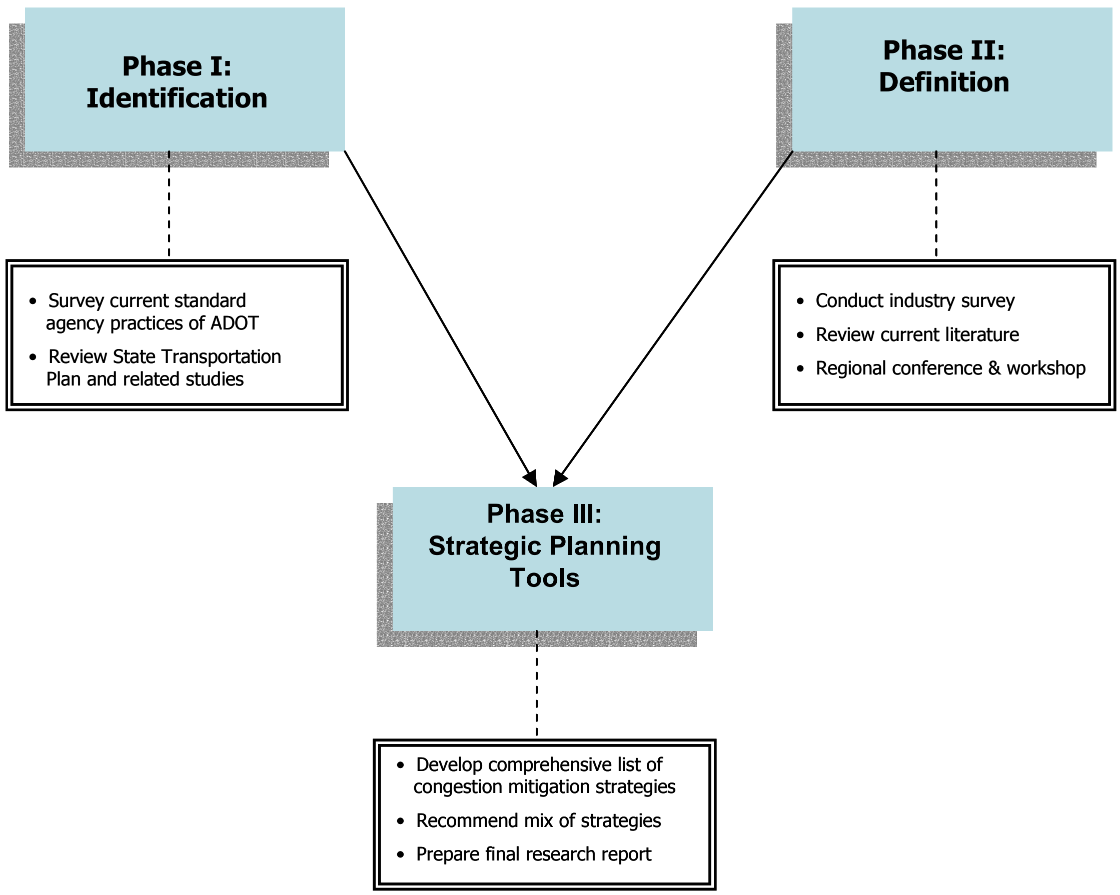

Figure 1 Project Overview

1.4 INTENDED USE OF RESEARCH RESULTS

The toolbox consisting of congestion mitigation strategies and a congestion index, developed through this research project, is intended to be used at the planning, programming and project levels by ADOT. This report provides basic information with the realization that work is required to develop the planning and programming capabilities described in this section. The toolbox can be used by ADOT to track statewide congestion and identify effective congestion remedies. These resources can be used at the planning level for determining applicable congestion mitigation strategies, assessing congestion levels statewide, setting policy level congestion indices for various subsystems of the State Highway System, costing congestion mitigation at the system level, establishing long range priorities for congestion mitigation, and assigning congestion mitigation benefits to alternative long range transportation plan strategies. The toolbox can be used at the programming level to incorporate congestion mitigation into specific projects that are programmed in the near future in order to address concerns and meet goals in specific locations of the State, to establish program objectives for congestion index levels, to estimate the cost of mitigating to specific index levels, to determine the congestion mitigation priorities for specific levels of mitigation funding, and to assign congestion mitigation benefits to alternative program strategies. Additionally, the toolbox can be applied at the project level to implement specific strategies and to assess the costs and benefits for incorporating these strategies into projects. Finally, the results of this study can be used by local and regional planning agencies in Arizona and elsewhere in developing congestion mitigation solutions at the project, programming and planning levels.

The toolbox created through this research project provides a comprehensive set of strategies that can be implemented to mitigate congestion on Arizona's state highways. In addition, the congestion index developed through this research effort provides a framework to allow the incorporation of the toolbox into ADOT planning and programming in order to identify and address congestion statewide. Insight and direction provided by TAC review and discussion, key ADOT staff oversight, and through the consultant team research yielded a vast well of resources that can be utilized in addressing congestion in Arizona.

1.5 REPORT ORGANIZATION

Chapter 2 outlines the outcomes of the research efforts in Phases I and II. Sections 2.2 and 2.3 present the baseline study within Arizona. Sections 2.4 and 2.5 describe the outcome of the study of nationwide perspectives on congestion issues, definitions and measurements. Section 2.6 highlights the outcomes of the one-day regional conference and workshop. The TAC guidance on the research project is outlined in Section 2.7. The Chapter ends with a summary of major issues in Section 2.8.

Chapter 3 highlights the performance-based environment within which ADOT operates. It describes how ADOT came to embrace a performance-based approach for doing business. It also describes the congestion-related performance measures that ADOT submitted in compliance to the 2001 State Legislature's request for such information. Lastly, Chapter 3 outlines the Governor's Vision 21 Task Force recommendations for performance-based planning and programming.

Chapter 4 provides an overview of the strategic planning tools developed in this research project. Section 4.2 outlines the congestion index while Section 4.3 provides an introduction of the congestion mitigation strategies developed for Arizona's State Highway System. The congestion index and mitigation strategies comprise ADOT resource toolbox.

Chapter 5 describes the process for selecting candidate strategies for inclusion in the ADOT resource toolbox. First the information defined for each strategy is discussed in Section 5.1, followed by a discussion on how candidate strategies for ADOT resource toolbox are selected in Section 5.2. Details on how the application of each field influences the selection of strategies are described in Section 5.3. Lastly, the recommended strategies are presented in Section 5.4.

Chapter 6 provides an overview of the relational database system that stores the recommended strategies presented in Section 5.4. It describes the rationale for using a relational database and for using MS Access.

Finally, Chapter 7 provides a summary of the research efforts and outlines the recommendations of the study.

The products generated in the three phases of the study, together with additional information used in the study, are included in the Appendixes.

2. IDENTIFICATION AND DEFINITION

2.1 INTRODUCTION

Phases I and II (see Figure 1) involved agency and industry surveys, as well as reviews of both statewide and nationwide planning studies. This chapter of the report outlines these various research tools employed to achieve the objectives of identifying congestion issues in Arizona and arriving at an acceptable definition of congestion on Arizona's highways. The TAC's guidance in these issues is also described. This Chapter also serves as the major source of information for the development of the strategic planning tools described later in Chapters 4 and 5.

2.2 CURRENT AGENCY PRACTICES IN ARIZONA

An Arizona agency survey was conducted to assess current practices for defining, measuring, and mitigating congestion within the State. The questions developed for the survey of key Arizona transportation stakeholders were based on the fundamental issues described in the project requirements in Section 1.2. The questionnaire administered in the survey is presented in Appendix A.

Fifteen local municipalities, counties, metropolitan and regional planning organizations, and key ADOT staff were surveyed as part of this effort. The selection of survey participants was guided by the TAC. Representatives from the following organizations participated in the survey:

- ADOT Kingman District.
- ADOT Prescott District.
- ADOT Traffic Engineering.
- ADOT Transportation Technology Group.
- Arizona Department of Public Safety.
- City of Flagstaff.
- City of Nogales.
- City of Phoenix.
- Pima County.
- Maricopa Association of Governments.
- RPTA / Valley Metro.

Results from the survey were collated and presented in the Pre-conference White Paper that was distributed during the March 5, 2002 Regional Conference and Workshop held at the Radisson Phoenix Airport Hotel in Phoenix, Arizona. The pre-conference document is included as Appendix D-1 in this report. Highlights of some key issues and the survey responses to those issues are described below.

2.2.1 Congestion, and Rural versus Urban Congestion Issues

All respondents agreed that congestion represents a very significant issue in Arizona with congestion mitigation being placed near the top of everyone's priority list. ADOT allocates large amounts of funding for mitigating congestion that includes capacity expansion to accommodate the existing demand as well as other congestion reduction strategies.

The respondents report that while motorists clearly do not appreciate congestion, little has been done in Arizona to survey customer satisfaction with the State's transportation system. Thus there is no metric to gauge customers' tolerance levels for congestion.

The issue of distinguishing rural versus urban congestion in Arizona received little overall attention from the respondents, possibly indicating that the topic of rural congestion is not traditionally in most agencies' focus. Those who commented on this issue noted that rural congestion is often related to through traffic (i.e., traffic passing through a community) and to events or popular tourist locations (e.g., the Grand Canyon or the Painted Desert). In addition, congestion in rural areas may occur during different time periods and days of the week, e.g., on Friday afternoons or Sunday evenings when travelers leave town or return from weekend trips. Urban congestion on the other hand is typically related to the AM and PM peak travel periods.

2.2.2 Congestion Definition and Measurement

The majority of the respondents relate the definition of congestion to the *Highway Capacity Manual* (HCM) Level of Service (LOS), with lower LOS indicating more congested conditions (refer to Table 1 for definition of the range of LOS). Congestion is normally considered to occur at LOS D or lower. ADOT has a goal of LOS B or better statewide with LOS D or better in the metropolitan areas. There is a strong view that LOS threshold should differ between urban and rural areas. LOS D is suggested as acceptable for urban areas and LOS C for rural highways. Level of service E or F is typically used as the threshold where the system starts to break down, with threshold levels varying by location. Breakdown threshold at intersections could be the overriding factor of system breakdown, typical in highly urbanized areas. It is important to note that some agencies do not have a formal definition of congestion.

Other measures of congestion used in the urbanized regions of the state include average delay per vehicle, visual observation of traffic queue lengths at major signalized intersections, and correlation of average daily traffic (ADT) and LOS.

2.2.3 Quantifying the Cost of Congestion

A few of the survey respondents referred to the Maricopa Association of Governments' (MAG) areawide congestion studies. However, it was pointed out that the MAG studies did not quantify the cost of congestion. A relevant study conducted by the Texas Transportation Institute (TTI) for the Phoenix urban area was also mentioned. The TTI study quantified the delay and fuel consumption caused by congestion delay and value of lost time. References were also made to the Congestion Management System Report and the Long Range Plan.

Table 1 Level-of-Service Definition

LOS	Roadway Segments	
A	Conditions of free unobstructed traffic flow with no delays, and traffic signal phases are sufficient to clear all approaching vehicles.	
B	Conditions of stable flow with very little delay, and a few signal phases are unable to clear all approaching vehicles.	
C	Stable condition, movements somewhat restricted due to higher volumes, but not objectionable to motorists.	
D	Movements are more restricted, queues and delays may occur during short peaks, but lower demands occur often enough to permit clearing, preventing excessive backups.	
E	Represents operations at lower operating speeds with volumes at or near capacity. Flow is unstable, and there may be momentary stoppages.	
F	Forced flow conditions where demand volumes exceeding capacity. Speeds are reduced significantly and stoppages may occur for short or long periods of time due to traffic congestion.	

Photo Source: Flint-Genesee County, Michigan, 2025 Long Range Transportation Plan

2.2.4 Congestion Mitigation Strategies and Data Collection

Current or planned congestion mitigation techniques include continuous use of the tools built into the Freeway Management System (FMS) such as Variable Message Signs (VMS) and ramp meters; promoting the use of alternative modes of transportation; traffic signal synchronization; network expansion including alternate routes; improved agency communications; more detailed studies of congestion; intersection improvements; increased funding for congestion mitigation programs; coordination of land use planning with transportation infrastructure improvements; adding capacity to highways and at intersections; truck-only lanes; light rail system; expansion of the bus transit system; improved signing and striping at minor intersections; city-to-city signal progression; HOV program; improved responses to collisions; and freeway service patrols.

Most of the respondents were not aware of data collection specifically relating to congestion. Some mentioned the data collected by the Phoenix FMS which include traffic volumes, occupancy and speeds. Others mentioned turning movements, queue lengths and approach delay at intersections.

2.2.5 Performance Measures for Strategies

Many respondents suggested a range of valid mitigation performance measures including the amount of travel to avoid congested areas, average delay time, customer feedback, reducing delay per vehicle, reducing accident rates, stopped delay at intersections, average speed point-to-point, number of stops in a given trip, LOS, ADT, one-hour peak volume, and travel time.

2.2.6 Congestion Management and Monitoring

In response to increasing congestion, some agencies are developing their own traffic monitoring systems. Congestion problems are typically reviewed on a case by case basis, district by district, and community by community. Often the word "congestion" is not used but many agency staff are constantly monitoring the street system to identify and try to remedy congestion. Within ADOT, TPD alone has traditionally been tasked with the systematic planning of improvements to reduce congestion. The ISTEA-mandated and now non-mandatory Congestion Management System program was never really implemented in Arizona. MAG and PAG (Pima Association of Governments) are administering the only monitoring programs.

2.2.7 Inevitability of Congestion

The majority of the respondents felt that congestion was inevitable. One pointed out the issue of latent demand for travel, which is not easily quantifiable, but of such magnitude that it is not cost effective to continue to build enough capacity to satisfy it without congestion. The survey asked the question “can we build our way out of congestion?” to which most responses were negative. Some expressed the need to consider a "big picture" approach to the problem, i.e., to consider other alternative modes of transport. A few mentioned a lack of political will to provide funding for road improvements.

2.2.8 Incorporating Air Quality, Energy Conservation, and Land Use Planning

Ongoing air quality, energy conservation, and land use planning studies in Arizona should be incorporated into the transportation planning process. By working and planning together with local jurisdictions and communities, congestion issues can be tackled more successfully. The idea of interaction between land use planning and transportation system planning is being explored at ADOT. Currently little can be done as each city controls its land use planning and there is no overall champion of this approach. A need was identified to assemble a smorgasbord of ideas to pick from to mitigate congestion.

The findings of the Arizona agency survey provided some good background during the workshop discussions. These findings also provided a good resource in the development of the congestion mitigation strategies toolbox in Sections 4 and 5.

2.3 REVIEW STATE TRANSPORTATION PLAN AND RELATED STUDIES

Initially the research team was directed to review the current State Transportation Plan and ten other documents. The research team found a need to review more document sources than the scope required. This body of research encompassed a wide range of studies including statewide studies, small area studies, community transportation plans, state corridor profile studies, and other state and federal studies related to congestion criteria and congestion mitigation strategies. A complete list of all the documents the team reviewed is included in Appendix B.

Goals, measures and techniques relating to congestion were extracted from these documents. The collated information provided a useful guide in the selection of appropriate congestion mitigation strategies in Sections 4 and 5.

2.3.1 State Transportation Plan

A review of the 1994 Arizona State Transportation Plan reveals goals and policies for maintaining a good transportation system. The goals are oriented to maintaining effective highway, rail, aviation, transit, pipeline, bicycle, pedestrian, multi-modal, and intermodal systems; ensuring connectivity, accessibility, safety; and using innovative technologies. Strategies to manage congestion include: telecommuting, traffic light coordination, expanded public transit, carpooling, automated traffic signal systems, ramp meters, changeable message signs, reversible flow traffic lanes, "real time" incident response, advanced driver information systems, intelligent vehicle highway systems, new highway construction, roadway reconstruction and widening, peak hour pricing, intersection improvements, access control management, traffic circulation, park and ride lots, transit centers, ridesharing, preferential parking for ride sharers, staggered work hours, public transit improvements, High Occupancy Vehicle (HOV) lanes, ramps and facilities, light/commuter rail, surveillance and control including FMS, monitoring and management systems, and construction traffic coordination.

2.3.2 Arizona Statewide Studies

Arizona statewide studies vary in depth and content. Congestion is defined by level of service (LOS) as a function of volume to capacity (V/C) ratio. Strategies to address congestion include operational improvements, physical improvements, collaboration enhancements for intermodal facilities, redesign of port facilities, installation of a dedicated commuter lane at the port of entry, other port enhancements, and the identification of short-term, mid-term, and long-term Intelligent Transportation System (ITS) techniques.

2.3.3 ADOT Corridor Profile Studies

Current ADOT corridor profile studies use the HCM methodology to calculate level of service as a measure of congestion. Recommendations to mitigate congestion are based on prevailing conditions. Mitigation techniques include widening of the roadway, other roadway improvements, intersection and interchange improvements, improvements to transit and other modes, access control, and ITS.

2.3.4 Small Area Studies

Small area studies typically define congestion by V/C ratio and LOS. Thresholds vary from a V/C ratio of 0.75 to 1.00. Moreover, indirect measures of V/C and LOS are sometimes used. For example, one study measured congestion by travel-time based performance measure that was translated to LOS while another study used ADT as a measure of V/C ratio. ISTEA legislation required that the following strategies be considered: travel demand management measures (TDM), traffic operations improvements (traditional), HOV measures, public transit capital improvements, public transit operational improvements (traditional), nontraditional modes, transportation pricing, growth management and activity center strategies, access management, incident management (information elements under ITS), and ITS. Particular mitigation strategies include: widening, intersection improvements, interchange reconstruction, interconnection of traffic signals, new roadways, extension of roadways, multi-use/bike lanes, sidewalks, transit system expansion and other transit features, passing lanes, turn lanes, access management, right of way preservation, traffic impact analysis, signal spacing, traffic signal optimization, effective intersection design, land use controls/strategies, market incentives, and alteration of timing or frequency of travel.

2.3.5 Other State & Federal Studies

Many studies use V/C ratio and LOS as a measure of congestion. One study identifies the threshold of LOS D for urban areas and LOS C for rural areas. Mitigation techniques include the application of the following: improvements that encourage people to carpool and use bus and transit systems, making existing highway systems more efficient, land use alternatives to manage growth in suburban fringe areas, strategic investments of mobility dollars in high priority corridors, ITS, traffic signals, ramp meters, incident response, traffic signal coordination, low cost enhancements for safety and traffic flow, traffic regulations and standards like signing, expanded transit services, transportation demand management, HOV lanes, park and ride facilities, coordination with local agencies to develop congestion mitigation strategies, acquisition of access control rights, urban bicycle connections across state highways, development of a mitigation partnering fund with contributions from local economic development for mitigating congestion impacts, safety program to reduce or prevent accidents, intersection improvements, travel demand management, and increased highway capacity, such as new lanes and new roads.

2.4 NATIONAL INDUSTRY SURVEY

The national industry survey used the same survey instrument as that used in the Arizona Agency survey. The respondents selected for the survey were transportation professionals in other state DOTs, the U.S. DOT, regional governments, university research centers, and private transportation and communication companies. The survey was carried out via telephone interview after survey participants were provided with a copy of the survey instrument. Research team member, Shawn Turner, of Texas Transportation Institute administered the interviews.

The objective of the national industry survey was to acquire an understanding of the profession's current focus with respect to reducing traffic congestion. The interviews attempted to validate current understanding of the most applicable definitions of congestion, as well as the commonly used congestion measures. Furthermore, the interviews sought to enhance knowledge about the tools that are now available or can be useful in the near future to combat or prevent congestion.

It was agreed by the TAC and the research team to carry out 10 interviews. Representatives from the following agencies were selected:

- Transportation Research Center, University of Washington
- California Department of Transportation (Caltrans)
- Metropolitan Transportation Commission, San Francisco
- Colorado Department of Transportation
- North Central Texas Council of Governments, Dallas-Ft. Worth
- Metropolitan Washington Council of Governments, Washington, DC
- Ohio Department of Transportation
- Houston-Galveston Area Council
- Oregon Department of Transportation
- New York State Department of Transportation

Highlights of some key issues and the survey responses to those issues are described below.

2.4.1 Congestion, and Rural versus Urban Congestion Issues

Most respondents indicated that congestion is a large-concern, high-priority issue in their jurisdiction and that it would not go away any time soon. Several respondents indicated that congestion was the highest-ranked transportation problem facing their agency.

Several agencies (all state DOTs) do account for rural congestion in their definitions by using different congestion thresholds for urban vs. rural areas. For example, the Oregon DOT defines congestion in terms of V/C ratios, but has “standards” that differ by area type and highway class. The Ohio DOT has similar definitions, defining congestion in urban areas as V/C ratios greater than 1.0, whereas rural congestion starts at 0.9 on rural highways.

Key rural and urban congestion issues were noted by several responding agencies:

- Growth management and how to deal with it— several areas are struggling to deal with a large growth in jobs and populations. The key question is how the transportation profession should respond.
- Effects of congestion on the economy and the movement of freight — several areas are concerned about how congestion affects local economies and disrupt efficient freight movement.
- Provision of more reliable travel— the concept of transportation system reliability was a concern for several areas, with some seeing an increased emphasis on operations as a way to improve reliability.

2.4.2 Congestion Definition and Measurement

The responding agencies appear to be split between defining congestion in terms of reduced speeds, levels of service below a certain threshold, or volume-to-capacity (V/C) ratios above a certain threshold. Several agencies use a mix of different definitions for different applications. For example, travel time runs are used for before and after evaluations, but V/C ratios are used for planning and programming purposes. Several agencies' definitions are currently being revised or transitioned from one type of definition to another.

2.4.3 Perception of System "Breakdown" or Threshold Level

Congestion or "breakdown" threshold varies between each of the responding agencies. Within each jurisdiction the congestion threshold mostly differed by the type of facility (e.g., NHS Interstate highways vs. significant state routes vs. local routes, etc.) and by area type (e.g., urban MPO areas, urban non-MPO areas, rural, etc.).

In relation to congestion definitions, most responding agencies defined their thresholds in terms of V/C ratio, LOS, or speed (in that order of frequency).

2.4.4 Congestion Mitigation Strategies and Data Collection

The responding agencies indicated a wide array of congestion mitigation strategies they are pursuing. These strategies include strategic capacity expansion, signal coordination and re-timing, bottleneck removal, improved bus service, car/vanpooling, HOV/HOT lanes, traveler information, special events and incident management, freeway service patrols, ramp metering and traffic control, flex-time and flex-place/telework, and access management. Most agencies are pursuing a wide range of strategies, whereas a few are pursuing or focusing on a distinct bundle of strategies, such as operational strategies.

Other issues of note were an increased emphasis on performance monitoring and reporting to customers, balancing mobility and accessibility in pedestrian environments, and using access management as a congestion mitigation tool.

In terms of data collection, most responding agencies indicated that they concentrate their congestion data collection on traffic volumes and facility characteristics (e.g., roadway geometry and cross-section data). Several agencies also supplement this traffic volume information with travel time/speed run data and archived data from traffic operations. Aerial photography is used in several areas to collect traffic densities (used in estimating LOS) and facility characteristics.

2.4.5 Selection Process of Congestion Mitigation Strategies

Most agencies select their mitigation strategies using a combination of both location-specific (project-by-project) and systemic processes. For example, some agencies have selected certain strategies (e.g., ramp metering and other operational strategies) that they are attempting to apply at congested locations. These same agencies, as well as others, use project level "investment" analyses to select appropriate mitigation strategies.

2.4.6 Congestion Management and Monitoring

Nearly all of the responding agencies have a congestion monitoring or management program. However, the connection between the congestion monitoring program and the project planning/prioritization process was not clear from the responses.

2.4.7 Quantifying the Cost of Congestion

The consensus was that although it is difficult to declare success when congestion is still present and in some cases still growing, most respondents felt that congestion would be much worse if congestion mitigation efforts were not attempted. The respondents recognized that it was difficult to estimate this "do nothing" effect, but that several agencies are attempting to quantify this in their performance assessments. Economic conditions, regional growth, tourism, and freight movement will continue to have an overwhelming effect on congestion. In some areas, this effect will be greater than can be mitigated with transportation solutions.

2.4.8 Performance Measures for Strategies

Valid performance measures of congestion mitigation strategies used by the agencies encompass the "usual suspects" to measure system performance. These "usual suspects" measures include person and vehicle travel, travel times, speeds, delay, LOS, V/C ratio, traffic density, traffic stops, and cost-benefit ratios. One respondent did mention his dissatisfaction with the "usual" performance measures and suggested a "market basket of transportation services" approach similar to the consumer price index. The responses indicated that there wasn't a single best measure to use, and that in many cases, several performance measures may be appropriate.

2.4.9 Inevitability of Congestion

Another key question for the survey respondents was "can we build our way out of congestion?" The short answer from most respondents was "not likely given current political will and economic realities." Environmental concerns and public approval are also factors that will limit the transportation professions' ability to reduce congestion. Several respondents indicated that in growing urban areas, the best that could be done is to slow the rate of congestion growth.

Much of the information gleaned from this survey indicates that Arizona is in a similar situation to its partner states throughout the country in striving to manage congestion, in incorporating performance based measures, and in attempting to tie congestion monitoring to planning and programming. Insights and information from this industry survey provide useful input into the strategic planning toolbox discussed in subsequent sections.

2.5 CURRENT LITERATURE REVIEW

A review of current literature was performed as the next step in the research effort to identify practical planning tools and mitigation strategies that can be used to help anticipate, detect and solve congestion problems on the Arizona State Highway System as they arise. The purpose of the literature review was to reveal current measurements, technologies, and strategies being implemented to measure, monitor, and mitigate congestion in the United States, excluding Arizona. A list of relevant literature reviewed in this study is detailed in the Bibliography.

2.5.1 Measuring Congestion

Measurement of congestion is critical in assessing the current status of congestion and the level of benefit derived by implementation of mitigation strategies. Performance measurement also plays a significant role in the **Congestion Mitigation Resources and Strategies for Arizona's State Highway System** research project. The *Highway Capacity Manual* methods of measurement are probably the most widely used in the United States (Transportation Research Board, 2000). The literature review documents HCM applications and limitations, including the *1998 MAG Regional Congestion Study's* (Traffic Research & Analysis, 2000) use of HCM methodologies. The Seattle Metropolitan Freeway System is cited in the review for their application of performance measures to assess system performance, site specific performance, and HOV performance. The literature review details performance measures from the "before" and "after" comparative *Twin Cities Ramp Meter Evaluation* (Cambridge Systematics, 2001) by the Minnesota DOT in 2001. Finally, the review gives comprehensive documentation of the findings from *NCHRP Report 398, Quantifying Congestion, Volume 1* (Lomax, T.J, et al., 1996a).

2.5.2 Monitoring Congestion

ITS technologies are a valuable congestion mitigation resource playing a key role in congestion data collection and in optimizing the efficiency of transportation systems. Technology savvy strategies are key ingredients in the strategies database developed through this research project. The literature review presents existing sensor technologies and data requirements for ITS from various sources. The review highlights information from an FHWA study that provides current information on the theory and specification of non-intrusive sensors; recent findings on traffic management tactics, algorithm descriptions and performance; and data requirements for various ITS strategies. The review documents current literature on real-time congestion detection. These sources relate current practices of freeway and surface street incident detection, and adaptive traffic control systems. The review also reports the findings of *NCHRP Report 398, Quantifying Congestion, Volume 2, User's Guide* (Lomax, T.J, et al., 1996b). The methodologies from Volume 1 of this report use measures which rely heavily on travel time and vehicle occupancy data. The literature review highlights findings from the NCHRP report and other sources which address approaches that can be taken to collect this data.

2.5.3 Congestion Mitigation Strategies

A search through current literature documenting congestion mitigation strategies revealed generally the same strategies. Four principal sources were used to develop a representative list of current strategies:

- *Houston's 2000 Travel Rate Improvement Program* (Greater Houston Partnership, circa 2001).
- *A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility* (Meyer, 1997).
- *Mid-America Regional Council (MARC) Enhanced Congestion Management System* (Cambridge Systematics, Inc., Dec. 2001, March 2001, Nov. 2000, and Jan. 2000).
- *Handbook of Selected Congestion Mitigation Techniques in the United States* (Crawford, et al., 1998).

Each of these sources is thoroughly detailed within the review to relate the application of congestion mitigation strategies by the agency or author. The text addresses funding and includes implementation examples within the jurisdiction and throughout the United States. Strategies in the Houston area were directed to build more capacity, manage demand, increase system efficiency, and change the urban scheme. *A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility* provides a descriptive and definitive multimodal strategy approach to enhance mobility and accessibility. *MARC's Congestion Management System* (CMS) defines a congestion approach through the development of performance measures, a data collection and monitoring program, congestion management strategies, and evaluation procedures for these strategies. The review presents the MARC toolbox of strategies, relates the types of performance measures used and highlights other key aspects of the CMS. The *Handbook of Selected Mitigation Techniques in the United States* enumerates the cost and impacts of various key congestion strategies for various locations throughout the country.

2.5.4 Summary

The literature review yielded the following recommendations:

- Develop criteria for performance measurement (congestion index).
- Identify techniques to collect or estimate congestion data.
- Develop strategies to mitigate and/or manage congestion in the State of Arizona.
- Develop evaluation procedures.

The complete literature review document is included in Appendix C. The detailed information on measurement, technology, and strategies gathered through the literature search was input along with the survey results and other gathered data into the development of the strategic planning tools created as part of this project.

During the entire research process, additional material came to light and information garnered through these additional sources was incorporated into the development of the congestion mitigation strategies database. One particularly valuable resource was the Chicago Area Transportation Study's *Congestion Mitigation Handbook* (CATS, 1998). Other documents, websites, and material that were found were also used to strengthen and develop the final deliverables.

2.6 REGIONAL CONFERENCE AND WORKSHOP

On March 5, 2002, the Arizona Department of Transportation held a conference and workshop on "Congestion Mitigation Resources and Strategies for Arizona's State Highway System" at the Radisson Phoenix Airport Hotel. Conference participants were introduced to the current research on congestion mitigation being conducted for the Arizona Transportation Research Center by the consultant team. The objectives of the event included familiarizing Arizona's transportation stakeholders with ADOT's ongoing efforts to study and reduce congestion on Arizona's highways.

The primary goals of the March 5 conference and workshop were to help understand the ways in which traffic congestion is effectively defined, measured, and dealt with, and, to begin building consensus around the issue of congestion mitigation in Arizona. The workshop's key objective was to begin a statewide discussion on best congestion definitions and performance measures to be incorporated into ADOT's planning and operations. The workshop provided an opportunity for Arizona's transportation stakeholders to share their thoughts and experiences on the subject. Through presentations and discussions, regional practitioners and national experts imparted perspectives on congestion mitigation practices in Arizona and elsewhere in the country.

Project champion Tim Wolfe, ADOT Assistant State Engineer, opened the conference session. ADOT Director, Victor Mendez greeted about fifty participants with a warm welcome and an overview of the conference and workshop's goals. The morning session that followed was devoted to presentations from eight speakers from the Consultant Team, ADOT, and other Arizona transportation agencies who provided highlights on congestion-related efforts in Arizona and similar efforts and research in other parts of the country. Their presentations covered a wide-range of topics from the technical definition and measurement of congestion to the actual state of congestion in Arizona's State Highway System.

The afternoon session was devoted to finding definitions, measures, and solutions for congestion in Arizona through workshop discussions. Two afternoon workshops were dedicated to group discussions on the following five congestion related topics.

- Definitions of Congestion.
- Congestion Mitigation Strategies (Supply and Demand Sides).
- Techniques for Evaluating and Comparing Congestion Mitigation Strategies.
- Rural Congestion.
- Institutional Issues and Policies.

Each topic was assigned to a workgroup with approximately ten participants. Each workgroup had a facilitator and a note taker. At the end of each workshop discussion, the note takers provided a summary of the deliberations. The following paragraphs highlight some of the major issues deliberated:

The workgroup focusing on definitions and measures decided that mitigating congestion on a statewide basis will likely benefit from classification by broad geographic categories, such as the four location types (metropolitan, urban, rural and activity center), as well as by facility types and other spatial and temporal attributes. It is clear that popular definitions of congestion require clarification, particularly where the public's perceptions are involved. The notion of acceptable versus un-acceptable congestion must play a role in this study. While the traditional congestion measures (LOS, travel delay) have obvious value, new - both broader and more refined - definitions need to be embraced to begin addressing the entire spectrum of the congestion mitigation issue. This discussion group benefited from a dynamic discussion on these and other congestion definition related sub-topics.

Within the strategies workgroup, various mitigation strategies for congestion were mentioned. These were grouped into categories including: Travel Demand Management, Transportation Systems Management (TSM), TSM Rural, Transit, Operations and others. The strategies cited for each category, together with some associated issues, were discussed in detail.

The evaluation workgroup acknowledged that congestion is a big and complex problem. They realized that congestion mitigation often requires simultaneous application of multiple strategies at different levels of the transportation system. Current political environment and available funding may effectively set limits on which measures can be used. Other factors and issues were also discussed with respect to evaluating congestion mitigation strategies.

Rural congestion is an integral part of this project and was given a great deal of attention during the workshops. Two main issues were tackled by this workgroup with respect to congestion in rural areas: definition of rural congestion and solutions to rural congestion. Some performance-based solutions were separately identified.

The final workgroup focused on institutional issues. They related that the current mode of operations of public agencies does not necessarily promote open discussion and cooperation on the issue of congestion mitigation. While it is logical to expect that all affected jurisdictions should be involved in decision making, the often conflicting agency goals may impair cooperation. The long range planning process can be used as a common platform for open communications between agencies where new ideas can be brainstormed and evaluated. Larger agencies, like ADOT, should work with local jurisdictions to implement selected mitigation strategies. Additional institutional issues were also defined.

Results of the discussion groups yielded considerable insight into each discussion item with emphasis on Arizona specific issues. The information gathered from both the presentations and discussion groups is detailed in a post-conference white paper attached in Appendix D-2. This information was added to the pool of data used to develop the congestion mitigation toolbox and congestion index.

2.7 TECHNICAL ADVISORY COMMITTEE PROJECT GUIDANCE

Seven Technical Advisory Committee meetings were held to provide direction to the consultant team. These meetings acted as working discussions. The information and guidance to the team shaped the deliverables and routed the research efforts to meet the specific needs of ADOT.

A primary concern from the beginning of this research effort was to equitably address both rural and urban congestion issues. This need to address rural concerns was established in the initial work scope and was reiterated by the TAC throughout the study. The study therefore gave specific attention to include the identification of congestion measures and mitigation strategies applicable in rural settings.

TAC guidance further shaped the course of the research project by replacing the task to conduct a formal benefit/cost analysis in favor of categorizing strategies by relative cost and giving additional focus to performance measures. This task was further refined to include a relative scale of benefits. In addition, the TAC was very much involved in deciding the major categories of information that were defined for each congestion mitigation strategy. They also provided comments into the selection process the research team pursued in selecting the suitable strategies for Arizona.

As the concept of performance measures was being researched, ADOT repeated the desire to be able to apply the resource toolbox from this study to ADOT's planning and programming. From the results of Phases I and II, in particular the workshop discussions on the definition and measurement of congestion, a consensus has evolved into further research by the consultant team and the incorporation of a congestion index into the research project. The development of the congestion index led to discussion of an implementation phase. The envisioned implementation phase includes the need to assess congestion statewide, further refinement of the congestion index for application to all parts of the State, and the setting of thresholds to be used in programming and prioritization of projects. Following the TAC's suggestion, the consultant team developed a work scope as described in Section 7.2.1 to complete the proposed "Phase II - Implementation" work.

2.8 SUMMARY

2.8.1 Congestion Definition

Results from the surveys, reviews of statewide and nationwide studies, and from the one-day regional conference and workshop all pointed to the direction that there is no single definition of congestion. Most common definitions of congestion relate to the *Highway Capacity Manual* Level of Service (LOS), with lower LOS indicating more congested conditions. In NCHRP Report 398, Lomax, et al., provide two working definitions for congestion:

- ***Congestion*** *is travel time or delay in excess of that normally incurred under light or free-flow travel conditions.*
- ***Unacceptable congestion*** *is travel time or delay in excess of an agreed-upon norm. The agreed-upon norm may vary by type of transportation facility, travel mode, geographic location, and time of day.*

Ensuing from the workshop discussions, it was clear that popular definitions of congestion require clarification, particularly where the public's perceptions are involved. The notion of acceptable vs. unacceptable congestion must play a role in the present study. In the workshop discussions, both groups were in unanimous agreement that there was a need to separate the definitions of congestion from the judgments about what is acceptable and what is not acceptable. This seems to imply a definition similar in nature to NCHRP 398's "congestion" and "unacceptable congestion" described above. Likewise there is a need to consider the audience (includes both technical and non-technical) in developing the congestion definitions and measures. Some opined mobility as a concept that should be considered (as opposed to congestion). They thought mobility was the term more applicable to rural areas. Mobility entails efficiency and comfort of travel. They also mentioned that congestion seemed to be more facility-oriented, mobility was user-oriented.

With respect to defining rural congestion, several state DOTs do account for rural congestion in their definitions by using different congestion thresholds for urban vs. rural areas. For example, the Oregon DOT defines congestion in terms of V/C ratios, but has "standards" that differ by area type and highway class. The Ohio DOT has similar definitions, defining congestion in urban areas as V/C ratios greater than 1.0, whereas rural congestion starts at 0.9 on rural highways.

2.8.2 Congestion Measures

The various research tools employed in Phases I and II to find the measures of congestion reveal that LOS, volume to capacity ratios, and travel delay are the most commonly used measures. Other measures of congestion used in the urbanized regions of Arizona include average delay per vehicle, visual observation of traffic queue lengths at major signalized intersections, and correlation of average daily traffic and LOS. Several agencies use a mix of different measures for different applications. For example, travel time runs are used for before and after evaluations, but V/C ratios are used for planning and programming purposes.

While the traditional congestion measures (LOS, travel delay) have obvious value, new— both broader and more refined— definitions need to be embraced to begin addressing the entire spectrum of the congestion mitigation issue. In the dynamic workshop discussions on these and other congestion definition related sub-topics, workshop participants were somewhat split on whether travel time-based or LOS measures were better. Some cautioned against using LOS and V/C ratio measures and thought the focus should be on travel time measures. Some felt that travel time may not fully address or capture the issues/needs outside metropolitan areas. Some opined the need to capture duration of congestion in the measure(s). Workshop participants clearly indicated a need for reliability measure(s) that captured the effects of incidents, weather, and other events. However, there was no consensus on which reliability measure is best suited for this purpose.

In addition, it was suggested to consider traffic density and traffic mix measures in addition to LOS and travel time measures. These measures might be appropriate in rural areas. It was also suggested to consider safety and passing opportunities as potential additional measures in rural areas. In addition, congestion measurements for rural context should be based on driver expectations and not just on classical or traditional level of service measurements. Lastly, there was the concern that route lengths used in data collection and analyses are critical. Delays can get smoothed out and lost if the sections are too long.

2.8.3 Rural versus Urban Congestion Issues

Rural congestion is an integral part of this project and was given a great deal of attention during the workshops. TAC members also put strong emphasis on addressing rural issues. Findings from the various research tools employed in the study indicate strongly the different congestion-related issues between rural and urban contexts. Urban congestion is typically related to the peaking characteristics (AM, PM and sometimes business hours) of travel mainly due to work related trips. Rural congestion on the other hand is influenced by a different set of factors such as the physical characteristics of transportation infrastructures (number of lanes, passing opportunities, etc.), type of demand (percentage of commercial vehicles, seasonal demand), and severity of accidents (high fatality due to high speed). A summary of key rural issues include:

- Rural congestion is often related to through traffic (i.e., traffic passing through a community) and to events or popular tourist locations (e.g., the Grand Canyon or the Painted Desert).
- Rural traffic is highly seasonal, thus congestion is likely to occur during different time periods and days of the week, e.g., on Friday afternoons or Sunday evenings when travelers leave town or return from weekend trips and during holiday seasons.
- Safety is a BIG issue in the rural context. Rural roads have a large proportion of road fatalities, thus creating recurring rural congestion.
- The mix of rural traffic has a high percentage of trucks and RV's.
- Lack of timely advance notice of rural bottlenecks and lack of reliable data collection to measure and monitor congestion is an issue.
- Lack of alternative routes is an important factor in rural congestion in Arizona, as well as lack of local transit alternatives and amenities including lack of bus pullouts in areas where bus services are available (these include school buses).
- Rural congestion involves the effects of weather and other environmental conditions.
- Behavioral aspects of rural drivers are an issue. Expectations among rural drivers could be different. Likewise, habits among local rural drivers can be very different than those of non-local drivers (through traffic). Socioeconomic factors may also affect drivers' attitudes. These behavioral aspects need to be considered when defining congestion in the rural context.

There is a need to educate non-local drivers to better handle rural conditions.

2.8.4 Mitigating Congestion

Findings from the first two phases of the study suggest that mitigating congestion on a statewide basis will likely benefit from classifying congestion by broad geographic categories, such as the four location types (metropolitan, urban, rural and activity center) described in the Pre-Conference White Paper (Appendix D-1), as well as facility types and other spatial and temporal attributes. However, the use of location types to classify congestion needs to be more clearly defined and delineated (e.g., metropolitan vs. urban). In the activity center location type, there may be a need to differentiate between commercial vehicle traffic at the border and recreational traffic. Both groups clearly agreed that expectations would differ by location and facility type.

In addition to the location types, there is merit to distinguishing congestion by facility types (access-controlled highway, major arterials, minor arterials, etc.) and characteristics (availability of alternate routes, probability of incidents/breakdown, strategic importance, etc.).

In terms of selecting mitigation strategies, most agencies use a combination of both location-specific (project-by-project) and systemic processes. For example, some agencies have selected certain strategies (e.g., ramp metering and other operational strategies) that they are attempting to apply at congested locations. These same agencies, as well as others, use project level "investment" analyses to select appropriate mitigation strategies.

Another issue of note was an increased emphasis on performance monitoring and reporting to customers.

2.8.5 Pool of Mitigation Strategies

The surveys and reviews resulted in a pool of strategies which are candidate strategies for the ADOT resource toolbox. This list of strategies was developed based on the surveys and literature reviews. Strategies specific to Arizona were also brainstormed by Arizona transportation stakeholders attending the regional conference and workshop. These strategies were all added to the draft list included as Table 2.

Table 2 Draft Mitigation Strategies by Category

STRATEGIES BY CATEGORY	
Access Management	
Access management	
Bicycle/Pedestrian Strategies	
Bicycle additions	Improve coordination/continuity for bike/pedestrian systems
Bike/walk incentives	Walk paths
Capacity Addition	
Collectors/distributors	Lane capacity addition
Construct additional lanes	Lane capacity improvement
Construct new freeways	Roadway additions
Double decking capacity expansion	Widen arterials from four to six lanes
Freeway to freeway connections	Widen highways
Construction	
A+B bidding	Lower rental rates for night work
Acceleration of construction	Maintain acceptable travel time within construction zones
Construction management	Phasing/scheduling of regional construction
Improved construction traffic control	Reduce length where construction speed limit applies
Lane rental concept	
Geometric Improvement	
Add shoulders	Minor grade adjustments
Bus pull outs	Providing passing zone
Construct additional climbing lanes	Realignment to improve sight distance and increase passing zones
Construct additional passing lanes	Reversible lanes
Construct short 4-lane segments	Right turn lanes
Dual lefts	Roundabouts
Grade separation	Special intersection treatments
Improved frontage roads	Turn outs
Intersection improvements	Uniform and consistent striping on roadways
Merge/diverge lanes	
Growth Management	
Adjust apartment rental agreements	Land use planning
Adjust bank loans	Rehabilitate/reconstruct/clean existing infrastructure
Adjust development approval	Reinvestment in neighborhoods, parks, and schools
Adjust regulations	Transit friendly land use planning
Adjust standard designs	Urban design treatments
Growth management	Urban renewal
Job / housing balance	
HOV	
24-hour HOV lanes	HOV lanes
HOV lane management	

Incident Management	
511 system	Incident management
Better agency communications	Incident reaction team
Better agency cooperation	Incident work teams
Different incident management equipment for rural areas	Partnerships with local enforcement and emergency management agencies
Freeway service patrol	Quick clearance law
Improved breakdown and accident location	Rural incident management
Improved breakdown and accident removal	Video/filming/GPS to expedite investigation
ITS	
Advanced Traffic Management Systems (ATMS)	Road Weather Information Systems (RWIS)
Advanced Vehicle Location	Rural district Operations Centers
Creating expectations and publicizing them	Smart corridors
Highway Advisory Radio (HAR)	Traveler information
Highway Closure and Restriction Systems (HCRS)	Variable Message Signs (VMS)
ITS	
Operations	
Access control	Ramp metering
Better traffic signals	Signal spacing planning
Freeway ramp control	Traffic signal coordination
Improve signal timing	Traffic signal synchronization
Raise speed limit	Truck restrictions
Other	
Driver education	Pre-treatment before snow event
Event management	Provide alternative routes
Integrating bridge crossings with highways	Public outreach programs
Interagency cooperation	Smarter institutional arrangements
Internet access to travelers	Snow and ice removal
Mitigation strategies for flooding	Yield signs on buses
Phone access to travelers	
Road Pricing	
Congestion pricing	Privatization of road facilities
HOV lane pricing	Tolling
Transit	
Bus Rapid Transit (BRT)	Promote public transit
BRT Right-of- Way (ROW)	Reduced transit passes
Downtown bus lanes	Subways
Dynamic routing	Transit additions
Expansion of basic bus routes	Transit enhancements
Improved transit service speed	Transit information
Light rail system	Transit operations
More rural transit service	Transit priority
Promote alternative modes	Well coordinated intermodal connections
Travel Demand Measures	
Alternative mode incentives	Park-and-ride
Carpooling	Parking supply or rate control
Compressed work program	Private/public partnerships
Demand side strategies	Remote work site programs
Employer-based programs	Safe park-and-ride facilities
Flexible work hours	Shift travel from congested areas
Guaranteed ride home program	Solicit business participation to promote transit
HOV bypass	Staggered work hours
Market-based approach	Telecommuting
Mode shift	

2.8.6 Intermediate Research Products

The first two phases of the research project were summarized in several milestone deliverable documents that are included in the Appendixes as follows:

- Review of Current Literature of Congestion Mitigation Research and Practices in the United States (Appendix C).
- Arizona Congestion Conference and Workshop Pre-and Post-Conference White Papers (Appendix D-1 and Appendix D-2, respectively).

3. PERFORMANCE-BASED ENVIRONMENT

ADOT operates in a performance-based environment. This started in the early 1990's when the Department began its measurement-based quality initiative for doing business. The *MoveAZ Plan Strategic Directions: Initial Long-Range Goals and Objectives* memorandum utilizes performance measures for evaluating progress. This long-term commitment has led to ADOT receiving the 2002 Governor's Award for Quality.

In the late 1990's ADOT met with the State's regional planning agencies and others in Casa Grande. From that meeting came a statement called the Casa Grande Resolve in which the participating organizations committed to a performance-based approach for transportation in Arizona. Subsequent to that agreement, ADOT has begun the development of a long-range performance based transportation plan that is scheduled for completion in 2004. It is expected that the results from this congestion mitigation project can be a significant input to the transportation plan.

In 2001 the State Legislature, through its Joint Committee on Capital Review, began requiring ADOT to submit quality-related performance measures for evaluating the Department's program. The Legislature has specifically requested the Department to submit congestion-related performance measures. These measures include:

- Percent of State Highway System with traffic volume over 100% of capacity during peak driving periods in Phoenix Metro area.
- Percent of State Highway System with traffic volume over 100% of capacity during peak driving periods in Tucson Metro area.
- Percent of State Highway System with traffic volume over 100% of capacity in balance of State.

The Governor's Vision 21 Task Force completed its work at the end of 2001. Among its recommendations was a proposed State Transportation Board and legislative requirement for all transportation planning and programming organizations in Arizona to utilize performance-based planning and programming. The Task Force further recommended that ADOT be legislatively required to develop a performance-based long-range transportation plan for a minimum time period of twenty years into the future. As a result of the Task Force recommendations, the Legislature passed HB 2660 that requires the Department to adopt performance-based planning and programming processes and system performance measures and factors and data collection standards. The legislation requires at least the following transportation system performance factors: system preservation, congestion relief, accessibility, integration and connectivity with other modes, economic benefits, safety, air quality and other environmental impacts, cost-effectiveness of a project or service, operational efficiency and project readiness.

The evolution of ADOT into a performance-based environment requires that the results of this congestion mitigation research project be presented in a format that enhances performance-based planning and decision-making. TAC guidance has been repeated through the duration of the study to ensure that project deliverables incorporate performance-based approaches.

4. CONGESTION MITIGATION TOOLBOX FOR ARIZONA'S STATE HIGHWAY SYSTEM

4.1 INTRODUCTION

The main objective of the research project was to develop a resource toolbox of congestion mitigation remedies appropriate for Arizona's State Highway System. The envisaged resource toolbox was to contain the recommended congestion mitigation strategies. In the course of the research study, however, the concept of a resource toolbox evolved to incorporate the concept of a congestion index. The congestion index was an offshoot of the search for the best definition of congestion, and appropriate congestion measures for urban and rural congestion problems. The TAC asked the research team to develop the congestion index methodology. Section 4.2 outlines the proposed congestion index while the full detail is given in Appendix E. Section 4.3 introduces the congestion strategies component of ADOT resource toolbox.

4.2 CONGESTION INDEX

The project's review of current literature sources verified that the measurement of congestion is critical in assessing the current status of congested roadway conditions, and the level of benefit derived by implementation of mitigation strategies. The *Highway Capacity Manual* methods of measurement are probably the most widely used in the United States. Review of Standard Practices by Arizona Agencies also verified that a majority of them relate the definition of congestion to the *Highway Capacity Manual* LOS, with lower LOS indicating more congested conditions. As the concept of performance measures was being researched, ADOT repeated the desire to be able to apply the toolbox output from this study within planning and programming. Discussions evolved into incorporation of a "congestion index" in the research project.

The term "Congestion Index" denotes a measure of congestion. For this study, the key congestion index is the "travel time index", where the measure of congestion relates to the time taken to traverse a particular stretch of road or the time from an origin to a destination. The travel time index is defined as the ratio of peak travel times to free-flow travel times. One of the advantages of this type of measure is that numerous methods can be used to derive the index values for certain facility types. Travel times can be directly measured or collected using a variety of techniques. The inverse of travel time, speed, can also be directly measured or collected. Empirical estimates can also be used.

Besides the travel time index, there are other travel time-based measures. These include:

- Delay per traveler measured in minutes per person. This measure is designed to resonate with travelers and other transportation system users by reporting delay in terms that travelers can understand and relate to.
- Buffer time index, which is a measure of travel time reliability.

Compared to other congestion measures, such as the Level of Service (LOS) and Volume to Capacity (V/C) ratio, measures based on travel time have the following advantages:

- Travel time is meaningful to a variety of audiences (both technical and non-technical),
- Travel time measures allow comparisons between different modes of transport,
- Travel time measures can be used to assess the impacts of transport decisions on land use and the transportation system, and
- Travel time can be related to decisions among travelers, shippers and agencies.

The travel time index can be adjusted to suit the rural context. For example, weighting factors can be used to account for the relatively lower congestion level in rural highways compared to urban roads. This reflects the nature of different rural congestion issues discussed in Chapter 2.

Following on the TAC's direction, the research team developed the proposed congestion index that could be implemented for the 6,200-mile State Highway System in the State of Arizona. The complete document for the Proposed Congestion Index is included in Appendix E. The document presents in detail the various travel-time based measures, their applicability to both urban and rural contexts, methodologies to derive these measures, data and data collection techniques, as well as discussions on setting mobility targets or congestion benchmarks.

The proposed congestion index for ADOT resource toolbox includes the following recommendations:

- Use the travel time index as the key measure of congestion.
- Utilize existing data and information systems to estimate congestion.
- Recognize that the congestion monitoring process will evolve over the next 5 to 10 years.
- Develop "mobility targets" (i.e., acceptable congestion standards) based on location, functional classification, and/or route level of development.
- Use mobility targets to differentiate between acceptable urban and rural congestion.
- Periodically examine and update mobility targets based upon congestion benchmarks and customer satisfaction.
- Consider a pilot project and/or phased implementation as a means to fully develop the congestion monitoring and mitigation program.

4.3 CONGESTION MITIGATION STRATEGIES DATABASE

Phase III of the research project requires the development of a database that will serve as a toolbox of mitigation strategies suitable for Arizona's State Highway System. This section provides an introduction for the congestion mitigation strategies resource toolbox developed to meet ADOT's requirements.

The development of the strategies toolbox takes into accounts the findings and recommendations from the identification and definition phases of the research project. Three relevant recommendations are: (1) classify congestion mitigation strategies by broad geographic categories, such as the four location types (metropolitan, urban, rural and activity center); (2) distinguish strategies by facility types (access-controlled highway, major arterials, minor arterials, etc.) and characteristics (availability of alternate routes, probability of incidents/breakdown, strategic importance, etc.); and (3) adopt a performance-based approach.

The above recommendations are further discussed in Chapter 5, which provides details of the selection process for the recommended strategies in Section 5.4. Results from the surveys and reviews presented in Section 2.8.5, provided a pool of strategies from which to pick candidate strategies for the ADOT resource toolbox.

Chapter 5 presents the details of the selection of the strategies, together with the recommended strategies, while Chapter 6 outlines the relational database system that stores the selected strategies.

5. SELECTION PROCESS OF RECOMMENDED STRATEGIES

This section of the report provides an overview of the approach by which the recommended congestion mitigation strategies were selected. Because the resource toolbox considers a broad range of possible strategies applicable to the Arizona State Highway System, the selection process excluded quantitative analysis such as analyzing the impacts of congestion mitigation strategies, quantitative evaluation of advantages and disadvantages of alternative strategies, and analyzing benefit/cost ratios for alternative strategies. Instead, the selection process used some qualitative assessment(s) as described in the subsequent sections.

5.1 INFORMATION DEFINED FOR EACH STRATEGY

This section outlines the contents of the congestion mitigation strategies toolbox described in Section 4.3. The consultant team used the wealth of relevant information from the various sources of information described earlier in Chapter 2. The attributes or fields defined for each strategy were presented to the TAC during the May 16, 2002 meeting. Following the initial review of the proposed data fields and their intended meaning, the TAC members and the consultant team engaged in an in–depth discussion of the database, its intended uses, target audience, and the specifics of its content and desired format.

The TAC agreed on major categories of information to be included in the strategies database. Specific fields are shown schematically in Figure 2. The field name "performance objective" was preferred to "performance indicator." In addition, a glossary of terminologies was included in the database following TAC's suggestion.

As per TAC direction, most of the fields in Figure 2 have "pick-list" items. For example, Geographic Location has six items to choose from: (1) Activity Centers, (2) Metropolitan, (3) Rural, (4) Special Venue, (5) Urban, and (6) All locations. Details of the "pick list" items for the other fields are listed in Appendix G.

The types of information defined for a strategy, i.e., the fields considered, have bearing on the selection of strategies for inclusion in the resource toolbox. Section 5.3 discusses the application of database fields.

5.1.1 Strategy

Strategies are specific actions for reducing congestion. They can only be further subdivided into variations of the strategy. For example, ramp-metering is a strategy. Examples of variations could include types of ramp-metering implementation such as single meters, double meters, meter bypasses, and variable-time meters. There may be different technologies or methodologies for delivering the strategy. Each strategy has a detailed description that gives a definition and provides details on where the strategy can be applied.

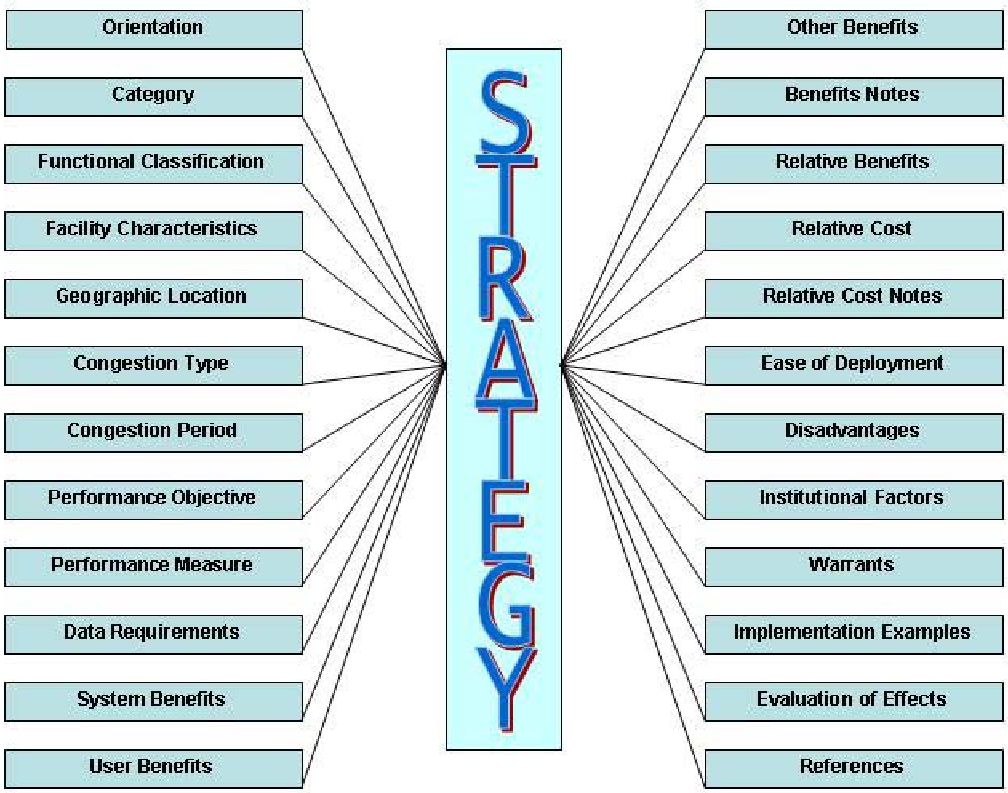

Figure 2 Fields Defined for Each Strategy

5.1.2 Orientation

The orientation of a strategy addresses whether it increases the supply (capacity) of the transportation facility or reduces the demand for the use of the facility. This is a broad classification field that will be used to generally categorize the groups of strategies.

5.1.3 Category

Categories are families of mitigation strategies such as freeway management, incident management or HOV (High Occupancy Vehicle) measures. Categories are subdivided into specific congestion mitigation strategies. For example, a freeway management category could include ramp metering, ramp closure, HOV or HOT lanes, freeway surveillance system, and incident response.

5.1.4 Application

The appropriateness of using specific congestion mitigation strategies is the function of a number of application variables. Descriptions of the application fields identified by the TAC are described below.

Functional Classification

This field relates to the roadway function classification currently used by ADOT as well as the Highway Performance Monitoring System (HPMS), which serves as the key source of information about traffic and roadway conditions on the State Highway System (SHS): Principal Arterial Interstate, Principal Arterial Expressway, Principal Arterial Other, Minor Arterial, Major Collector, Minor Collector and Local.

Facility Characteristics

Many characteristics of State Highways and their supporting road networks determine what congestion mitigation measures are feasible. These characteristics include access control, adjacent development, environment, facility expansion feasibility, frequency of access points, number of lanes, terrain, vehicle mix, and vertical and horizontal geometry. For example, a truck lane would not likely be used on facilities with low truck volumes, but might be appropriate for routes with high truck volumes and long sustained uphill grades with few passing opportunities.

Geographic Location

Some congestion mitigation strategies are only appropriate for certain geographic locations. The geographic locations selected for this work are metropolitan, urban, rural, activity centers and special venue.

Congestion Type

Congestion can be classified into several types that are important to the selection of appropriate mitigation strategies. They include recurring, non-recurring, predictable, unpredictable, and special event congestion. Recurring in this sense is congestion that is expected to occur, but may or may not be on a predictable basis. For example, peak hour congestion is recurring and predictable. Traffic incidents are recurring, but not predictable. A one-time congestion causing planned event will be non-recurring, but predictable.

Congestion Period

The time that congestion will occur is an important factor in determining the applicability of a mitigation measure. All day, all year, off-peak, peak hour, seasonal, and weekend are important timing issues for mitigation strategies.

5.1.5 Performance Objective

Objectives are intended to identify what the congestion mitigation strategy is trying to accomplish. Reduction in travel time will certainly be an objective of most strategies. Other indicators, such as reducing trips, reducing trip lengths, increasing transit and carpool usage, separating vehicles traveling at different speeds, reducing processing time and improved traveler direction are all objectives that will promote reducing congestion.

5.1.6 Performance Measure

Performance measures are the measurable factors used to assess the quantitative benefits of implementing a congestion mitigation strategy or clusters of strategies.

5.1.7 Data Requirements

Data is essential in quantitatively assessing the performance of the mitigation strategies. It is recognized that data is typically expensive to obtain, and to the extent possible existing reliable sources should be used. Some critical data may not be available from the current, standard sources used by ADOT and may need to be collected. Otherwise, only qualitative assessments of mitigation measure success will be possible.

5.1.8 Benefits

A successful congestion mitigation strategy should be expected to benefit the roadway system, the roadway user, and may bring other, indirect benefits as well. Three separate data fields are defined to capture this information:

System Benefits

Examples of system benefits include improved level of service, increased vehicle occupancy rates, higher load factors on buses, and reduced queue lengths in no-passing areas. These are benefits important to transportation professionals.

User Benefits

Examples of user benefits include reduced trip time, congestion avoidance, fewer vehicle conflicts, reduced accessibility and waiting times, and reduced driver frustration.

Other Benefits

Many strategies will provide benefits beyond congestion relief. Safety, reliability, connectivity, resource conservation and environmental protection are examples of non-congestion related benefits.

In addition, two other fields were defined to express benefits: (1) "*Benefits Notes*" is added to textually describe the benefits of a given strategy, and (2) "*Relative Benefit*" specified generally at a scale that attempts to quantify the system, user, and other benefits. It uses a relative scale such as "low," "medium" and "high." An additional category, "varies widely," is included to define relative benefits for strategies that vary highly depending on context and location.

5.1.9 Relative Cost

These are relative dollar costs (low, medium, high, and varies widely) specified according to some scale that could be related to the location and amount of traffic. The relative cost is meant to fall within the following rough categories: less than $100,000 for "low," between $100,000 to one million for "medium," and greater than one million for "high."

Where available, additional information is provided regarding the cost and this is stored in a separate field called "*Relative Cost Notes*."

5.1.10 Ease of Deployment

The relative ease with which a strategy could be deployed was considered to be an important issue. Categories for this field include: “difficult,” “medium,” “easy,” and “overcome institutional hurdles.”

5.1.11 Disadvantages

In many cases there are going to be disadvantages, in addition to monetary cost, to implementing a particular congestion mitigation strategy. It is important to know what these disadvantages are before applying the strategy or strategies. For example, in order for an HOV lane mitigation strategy to be successful, congestion must remain significant for SOVs.

5.1.12 Institutional Factors

ADOT will not have exclusive control over many of the congestion mitigation strategies that could be effective. This will require coordination and, in many cases, primary action by other organizations. Issues of control include coordination, decision-making, planning, funding, implementation and operation.

5.1.13 Warrants (Threshold)

Warrants are the congestion conditions that trigger the consideration or implementation of a congestion mitigation strategy or strategies. These are akin to standards of system performance. Consequently, warrants should flow from the performance measures and associated data used to assess the performance.

5.1.14 Implementation Examples

Examples of where a particular congestion mitigation measure has been used successfully or has failed provide some guidance as to the appropriateness of its use at other locations.

5.1.15 Evaluation of Effects

This field describes what software or other tools are available and can be applied to determine the effect that a strategy has had after it has been implemented.

5.1.16 References

A list of references is provided for individual strategies for which specific examples, warrants, or other pertinent information was drawn.

5.2 SELECTION OF CANDIDATE STRATEGIES

A master list of congestion mitigation strategies considered in this study resulted from a comprehensive literature review, interviews, feedback from questionnaires and the congestion workshop described in Section 2. From this master list, a set of recommended congestion mitigation strategies were selected for presentation in this report. The selected strategies were chosen on the basis of relevancy to the characteristics of Arizona and its State Highway System. The characteristics considered are:

- Rapidly growing state.
- Mobile lifestyle.
- Low density metropolitan areas.
- Development focus along state highways.
- More than 80 percent of state is government or tribal land.
- Tourism is a major industry.
- Large distances between urban centers.
- Few parallel routes in rural areas.
- Significant terrain issues.
- Significant percentage of trucks and recreational vehicles on rural system.
- Several border crossings, including international borders requiring vehicle processing.
- Significant interstate travel on rural system.

One of the major issues raised during the workshop, and in the TAC meetings, is the need for a significant rural as well as urban focus of congestion mitigation strategies. The need to define appropriate performance measures that would not be biased against rural congestion problems was repeatedly emphasized. Thus, the above characteristics considered in the selection of strategies included a rural focus.

5.3 APPLICATION OF DATABASE FIELDS

The following paragraphs discuss the usage of several of the fields discussed in Section 5.1 in evaluating and selecting congestion strategies for implementation.

5.3.1 Performance-related Goals, Factors, Objectives and Measures

Congestion mitigation strategies can enable the achievement of many performance-related goals and objectives. Conversely, the performance measures used to evaluate success in achieving these goals and objectives can be used to measure the success of congestion mitigation strategies. In the development of the Arizona Long Range Transportation Plan, a number of long-range goals are being proposed in support of a mission statement for Arizona's transportation system. These goals can be represented by performance factors that suggest specific objectives and strategies for action. The performance factors can be described and measured with more detailed performance measures. The Arizona Long Range Transportation Plan is in the early stages of development, so it is only possible to give illustrative examples of how congestion mitigation strategies can provide direct support for the Long Range Plan.

Long-range transportation goals and associated performance factors under consideration are given in Table 3.

Table 3 Long-Range Transportation Goals and Performance Factors

Goals	Performance Factors
Access and Mobility. To provide a reliable and accessible multimodal transportation system that provides for the efficient movement of people and goods.	Mobility, Reliability, Accessibility and Connectivity.
Economic Vitality. To provide a multimodal transportation system that improves Arizona's economic competitiveness and provides economic opportunities for all Arizonans.	Economic Competitiveness and Accessibility.
Stewardship. To provide a balanced, cost-effective approach that combines preservation with necessary expansions and coordinates with local and regional transportation and land use planning.	Preservation, Mobility and Smart Growth.
Environmental Sensitivity. To provide a transportation system that enhances Arizona's physical and cultural environment.	Resource Conservation, Environmental Protection and Context Sensitive Design.
Safety. To provide safe transportation for people and goods.	Safety.

5.3.2 Examples of the Application of Congestion Mitigation Strategies to a Performance-based Approach

The following examples are provided to show how congestion mitigation strategies can be directly used in support of the State Transportation Plan's performance-based approach:

Example 1: Corridor or Freeway Management System

Goals Supported:	Access and Mobility, Safety, Economic Vitality, Stewardship and Environmental Sensitivity.
Relevant Performance Factors:	Mobility, Reliability, Accessibility, Connectivity, Safety, Economic Competitiveness, Preservation, Smart Growth, Resource Conservation and Environmental Protection.
Example Objectives Supported:	Increased travel speeds, Accident reduction, Improved access to activity destinations, Preserve functionality of State Highway System, and Increased energy conservation.
Example Performance Measures (for example objectives)*:*	Average travel speed during peak hours, Number of accidents per year, Point-to-point access time to activity destination, Average length of trip on state highway, and fuel consumption per mile.

Example 2: Acquire Access Control

Goals Supported:	Access and Mobility, Safety, and Stewardship.
Relevant Performance Factors:	Mobility, Reliability, Safety, and Smart Growth.
Example Objectives Supported:	Enhance levels of circulation, Reduce delay at access openings, Accident reduction, and Coordinated transportation and land use development.
Example Performance Measures (for example objectives)*:*	Average travel speed during peak hours, Number of access opening per mile, Number of accidents per year, and number of State/owner access agreements per mile.

Example 3: Widen Roadway Shoulders

Goals Supported:	Access and Mobility and Safety.
Relevant Performance Factors:	Mobility, Reliability, Accessibility, and Safety.
Example Objectives Supported:	Maintain and enhance levels of circulation, Improve availability of highway travel lanes, Integrate bicycle facilities into highway improvements and Accident reduction.
Example Performance Measures (for example objectives)*:*	Average travel speed, Number of hours per year of restricted travel lane use, Number of miles of highway considered reasonably safe for bicycle usage, and Number of accidents per year.

These examples clearly illustrate how congestion mitigation strategies and associated performance measures can be used to support multiple goals, performance factors and objectives that become a part of the long-range state transportation plan. In analyzing congestion mitigation strategies for application to any segment of the State Highway System, the analysis should address how the strategies under consideration, together with associated performance measures, support the goals, performance indicators and objectives of the long-range state transportation plan.

Table 4 on the following pages provides an alphabetical list of the performance measures identified for use with the proposed congestion mitigation strategies for the Arizona State Highway System. These performance measures should be considered for use in developing the long-range state transportation plan.

Table 4 Alphabetical List of Performance Measures in the Strategies Toolbox

Accessibility index
Accident rates
Accident rates for equipped vs. non-equipped vehicles
Accident Risk index
Accidents at major intermodal facilities (e.g., railroad crossings)
Accidents per VMT or PMT
Administrative efficiency improvements
Amount/proportion of traffic diverted
Average cost per lane-mile constructed
Average duration of incident
Average service times
Average speed
Average travel speed by heavy vehicles
Average travel time by heavy vehicles
Average travel time from origin to destination
Average trip length
Average vehicle occupancy
Cost for transportation system services
Cost per passenger
Cost per ton-mile
Cost savings
Cost-benefit measures
Customer perception of safety
Customer perception of urban quality
Customer perceptions on travel times
Customer satisfaction
Delay
Delay on minor street
Delay per ton-mile
Delay per vehicle
Delay reductions
Difference between change in urban household density and suburban household density
Duration of queues
Economic cost of crashes
Economic cost of lost time
Effects on business
Environmental factors
Facility usage
Freeway mainline/ramp accidents
Frequency of transit service
Fuel consumption per VMT or PMT
HOV lane travel speed
HOV lane travel time
HOV use
Incident detection time
Intersection delay
Intersection level of service
In-vehicle travel time
Jobs created or supported (directly and indirectly)
Level of service
Lost time due to congestion
Maintenance costs
Miles of congested roadway
Miles/intersection with access control
Mode share/shift
Mode split
Number of accidents involving hazardous waste
Number of accidents per capita
Number of accidents per ton-mile
Number of accidents per VMT

Number of accidents per year
Number of breakdowns
Number of carpoolers placed by program
Number of construction-related fatalities
Number of days in air quality noncompliance
Number of high accident locations
Number of people working at home
Number of stops
Number of trips being subsidized
Numbers of bridges with vertical clearance less that x feet
Occurrence of secondary incidents
On-time arrivals
Origin-destination of travel times
Overall mode split by facility or route
Park-and-ride-lot utilization
Parking utilization
Passenger trips per household
Peak load factor
Pedestrian volumes
Pedestrian-bicycle accidents
Percent walking or using bike by trip type
Percentage of employment sites with in x miles of major highway
Percentage of on time transit
Percentage of population/employment served
Percentage of population exposed to noise above certain threshold
Percentage of population within x minutes of y percentage of employment sites
Percentage of projects rated good to excellent
Percentage of region's mobility impaired who can reach specific activities by public transportation
Percentage of roads and bridges below standard condition
Percentage of trips in peak hour
Percentage of VMT on roads with deficient ride quality
Person hours traveled or PHT
Person miles traveled or PMT
Person throughput
Person trips
Ramp queue lengths and delays
Remaining service life
Response time to accidents
Revenue
Roughness index for pavement
Savings in vehicle hours per weekday or year
Schedule reliability
Service miles between road calls for transit vehicles
Throughput
Tons of pollution
Traffic volume on segments used for diversion
Traffic volumes
Transfer time
Transit ridership
Travel time
Vehicle age distribution
Vehicle hours traveled or VHT
Vehicle miles traveled (VMT) by congestion level
Volume of cyclists
Volume throughput
Volume-to-capacity ratios
Wait time

5.3.3 Location Considerations in Applying Congestion Strategies

Location is a major consideration in determining congestion. As defined briefly in Section 5.1, some congestion mitigation strategies are only appropriate for certain geographic locations. There are at least four different location types that should be considered in defining congestion. These are metropolitan, urban, rural and activity center. Following is a discussion of how congestion can be defined for each of these locations.

Metropolitan Area Congestion

For Arizona, this means the Tucson and Phoenix metropolitan areas. For most State Highways in metropolitan areas, there is full or partial access control. Travel speed and time delay are commonly accepted definitions for congestion in metropolitan areas. These are usually associated with peak travel hours when the number of vehicles exceeds the capacity of the roadway. Peak hour congestion is anticipated by road users and is probably to some extent tolerable. Congestion in metropolitan areas can also be viewed in terms of the close spacing between vehicles, both laterally and front and back on high volume highways. This leads to blocked views around large vehicles causing substantial numbers of accidents. There is also a high accident rate in locations where there is both congestion and large amounts of weaving. Congestion may also occur during non-peak hours in metropolitan areas. Non-peak travel congestion may be unanticipated or otherwise unacceptable to the highway user. Examples include inefficient intersections, construction zones, slow-moving vehicles and accidents delays not associated with the expected time specific travel delays. Metropolitan area congestion occurs year around.

Urban Area Congestion

As with metropolitan areas, travel speed and time delay are indicators of congestion. However, the delays are usually not as long as in metropolitan areas where the urban trip length is longer. State Highway congestion in the non-metropolitan urban areas of the State differs from metropolitan congestion in a number of ways. In most cases State Highways, other than Interstate, do not have substantial access control. They function as arterial streets and likely are the most important streets in the urban area. Therefore, the causes of congestion in urban areas are considerably different than metropolitan areas. Rather than lane capacity, congestion is normally the result of side friction due to many intersections and driveways. Pedestrians, bicycles, and parked or stopped vehicles (such as buses) are factors contributing to urban congestion. Urban area congestion may also be highly seasonal as the result of recreational and winter visitors.

Rural Congestion

Rural congestion can be the result of many factors. In some corridors, vehicular demand is approaching the metropolitan definition of lane capacity. High densities of trucks and recreational vehicles can contribute to the feeling of congestion although travel time and speed may not be materially affected. Slow-moving vehicles, coupled with lack of passing opportunities because of poor roadway geometry or high traffic volumes, can result in considerable speed reduction, delay and accidents (for risk takers). Construction zones often result in many miles of reduced number of lanes and speed, resulting in congestion. Emerging urbanizing areas along State Highways lead to increased side friction because of intersections and driveways. Accidents along rural highways may lead to long hours of delay.

Activity Congestion

Congestion can be associated with specific activities on or adjacent to highways. Processing time for vehicles at border crossings can be substantial. Access to and egress from State Highways for high attendance events may lead to congestion on the highway. Recreational destinations adjacent to State Highways produce localized congestion points. Adjacent industrial activities can produce substantial numbers of heavy slow moving vehicles entering, leaving or crossing a State Highway, resulting in congestion.

5.3.4 Orientation of Mitigation Strategy

Congestion type and location, timing, and government transport policies are some factors that influence the orientation of mitigation strategies. Intersection delays in growing urban centers can be mitigated in the short term through signal improvements such as signal coordination or smart corridors. These strategies are supply side measures. In the long term, transport policies could be aimed at improving demand side measures through promotion of alternatives such as provision and improvement of transit services.

5.3.5 Technological Considerations

Availability, cost and the type of technology to adopt are important considerations in selecting congestion mitigation strategies. In ITS (Intelligent Transportation Systems) applications, for example, compatibility of technology is an important issue. Technology chosen must be adaptable for integration with other systems. For instance, electronic tolling systems technology must be capable of being integrated into a broader system of advanced traffic management systems and advanced traveler information systems.

In most cases cost is an overriding factor in the selection of appropriate strategies. With most governments experiencing budget squeeze, low cost solutions are always preferable, as long as they address the problem. For example, AVL (Advanced Vehicle Location) systems are technologies that can greatly enhance bus operations/services. This technology, however, comes with a price. Two-way radios are low cost solutions to track down bus locations.

5.3.6 Facilities for Application

Facility characteristics are an important consideration in the selection of congestion mitigation strategies. Route function, access control, highway geometry and right-of-way restrictions are factors that should be considered in making decisions regarding the types of congestion mitigation strategies to use.

Route Function

Route Function is associated with level of development (LOD) and functional classification. State highways with LOD 1 or 2 and functional classifications as principal arterials will generally be associated with longer, higher speed trips. Congestion mitigation strategies for facilities with these functions could focus on access control, discouraging short trips and separating slow and fast moving vehicles. State highways with LOD of 4 or 5 and functional classifications as collectors will generally be associated with shorter and lower speed trips with substantial property access. Congestion mitigation strategies for these types of facilities could focus on maximizing safe throughput at lower speeds.

It is important to note that the current database setup does not define an LOD for each strategy. It is anticipated that the LOD attribute will be considered in the next phase of ADOT's congestion mitigation efforts where the resource toolbox (congestion mitigation strategies and congestion index) developed in this project will be tested for practical application.

Access Control

Access Control influences the facility volume and determines the amount and location of side friction. More access for ingress and less access for egress will generally result in more congestion. Methods for controlling ingress and improving egress should always be considered in a potential list of congestion mitigation strategies for a facility.

Highway Geometry

Highway Geometry will both suggest and restrict the kinds of congestion mitigation strategies that are appropriate for a facility. Highway geometry may lead to volume and passing restrictions and lane blockages. Median width and side slopes may restrict the kinds of congestion mitigation measures that can be considered. It is crucial to identify geometry related congestion on a facility in order to select appropriate congestion mitigation measures. For example, vehicle mix where proportion of heavy vehicles is high requires careful consideration of road geometric design. Poor geometric design can lead to high accident occurrence.

Right-of-Way

Right-of-way (ROW) width may be restricted by ownership, cost or adjacent development. The federal government or quasi-federal organizations, such as Indian tribes, own much of the ROW adjacent to state highways. Such ownership often makes acquiring additional ROW difficult at best, suggesting the use of congestion mitigation strategies that do not require or at least minimize acquisition. Adjacent ROW may be very valuable or developed to the extent that acquisition is not feasible— again suggesting congestion mitigation strategies that do not require additional ROW acquisition. ROW restrictions may make facility expansion impractical.

5.3.7 Types of Congestion for Mitigation

Congestion can be classified into recurring and non-recurring, predictable and unpredictable, special event, and duration categories. The type of congestion influences the appropriate mitigation strategies to be considered.

Recurring and non-recurring refers to whether or not congestion occurs on a relatively frequent basis. For example, accidents causing congestion may occur relatively frequently on a segment of high volume urban freeway. These accidents would be considered recurring, and strategies for rapid response to clear these accidents would mitigate congestion. On the other hand, an infrequent accident may cause congestion along a rural section of low volume highway. This accident would be considered non-recurring and call for a different mitigation strategy such as rerouting traffic.

Predictability refers to the ability to forecast when congestion will occur. Peak-hour urban and ports-of-entry congestion are predictable, and mitigation measures such as corridor and facility management can take advantage of this predictability. Congestion causing traffic accidents are not predictable. Mitigation measures that facilitate response will be beneficial for handling unpredictable congestion. Road users may be less tolerant of unpredictable congestion.

The duration of congestion influences the mitigation measures to be considered. If congestion occurs for long periods on a predictable and recurring basis, mitigation measures for increasing capacity or reducing demand during these times may be appropriate. If congestion occurs only for short periods and on a non-recurring basis, mitigation can probably be ignored.

The congestion mitigation strategies database provides guidance on the congestion types that each strategy could best address.

5.3.8 Warrants for Considering the Use of a Strategy

The first question is: "When is congestion sufficiently bad to do something about it?" This question can be answered by adopting measurable standards that if exceeded trigger the consideration of congestion mitigation strategies. The travel time index discussed in Appendix E provides the performance measure upon which to assign performance standards or mobility targets. If the mobility target for a segment of State Highway is exceeded, then considering the use of congestion mitigation strategies is warranted. Clearly, mobility targets will vary by location and will be influenced by many factors such as route function and importance, type of congestion, traffic volume and mix, adjacent development, time of day, week and season, terrain and public expectations. ADOT should consider adopting a mobility policy, and developing from this a comprehensive plan of mobility targets for the State Highway System.

The second question is: "If congestion mitigation is warranted, what measures should be considered?" The key to answering this question is to determine the causes of the congestion and to select those strategies that warrant consideration for mitigating the effects of those causes. The congestion mitigation strategy database identifies warrants for selected mitigation strategies.

5.3.9 Advantages and Disadvantages for Using a Strategy

The use of any congestion mitigation strategy has inherent advantages and disadvantages. These include implementation time, cost, political acceptability, system and user benefits, and short- and long-term results. These inherent features should be considered in selecting appropriate strategies.

Some congestion mitigation strategies take considerable time to implement, possibly years. This may not be a problem if the strategy is to be implemented for an emerging or projected future congestion problem, but is an obvious disadvantage if mitigation is needed now. The ability to quickly implement a strategy is an advantage.

Obviously, low implementation cost is an advantage, and high cost is a disadvantage. Conversely, high cost strategies often provide much larger user benefits than low cost strategies.

Obtaining political acceptance is key to implementing many congestion mitigation strategies. Political acceptance may be difficult to achieve for strategies that actually or are perceived to have adverse, social, lifestyle, environmental and economic impacts, or place added burden on the transportation facilities of other agencies. Obtaining political acceptance also may be a problem if ADOT does not have full control over the decision-making and implementation processes. Lacking political acceptance at the time of initial consideration of a congestion mitigation strategy is a disadvantage.

High user benefits are an advantage for implementing a strategy. User benefits can be measured in terms of improved travel time index, but there may be other benefits (or dis-benefits) in terms of safety, reliability, accessibility, connectivity, preservation, smart growth, resource conservation, environmental protection and transportation for the disadvantaged.

In some congestion situations short-term results from implementing congestion mitigation strategies are advantageous, and in others the advantage goes to long-term results. Generally, short-term results are needed to mitigate an immediate problem, while long-term results are sought from strategies that apply to developing or expected future congestion problems.

5.3.10 Relative Cost

The cost for implementing a congestion mitigation strategy can be expressed in many ways – monetary, economic, environmental, social and political. Actual evaluation of these costs can only take place in the context of a specific project or location because of the large variability that can occur. Such cost analysis should be included in the selection of strategies for a specific location. Considering the diverse strategies being considered in this study, the focus is only on relative monetary cost to give some understanding for budgetary requirements for implementing a particular congestion mitigation strategy. As mentioned earlier in Section 5.1, three ranges of relative cost are defined:

- "Low" is less than $100,000.
- "Medium" is between $100,000 and $1,000,000.
- "High" is greater than $1,000,000.

It should be recognized that these are only estimates of the probable range of cost for a given strategy and that the actual cost will be location specific.

5.3.11 Institutional Issues

The selection and implementation of many congestion mitigation strategies should include the involvement of agencies outside ADOT. In some cases the authority to plan, design, fund, implement and/or operate a congestion mitigation strategy will lie with other organizations or jointly between ADOT and other organizations. Even in cases where ADOT has full authority over a strategy, coordination with other organizations may be required because of potential impacts of the strategy on those organizations' facilities or operations or on public issues outside transportation, such as the environment and economic development.

ADOT should carefully evaluate the institutional consequences of any proposed congestion mitigation strategies and involve affected organizations in the project process.

Institutional issues were a topic of roundtable discussion at the Conference and Workshop on Congestion Mitigation Resources and Strategies for Arizona's State Highway System held on March 5, 2002. The following key points were made during the discussion and should be considered by ADOT when considering congestion mitigation strategies for implementation.

- Congestion issues can be viewed as general operations and planning issues.
- There is a need to work local planning issues into congestion mitigation planning.

- Parochialism is a major concern. Agencies have conflicting missions, values, goals and objectives. Agencies, such as ADOT, MCDOT, MAG and RPTA have institutional cultures that tend to think only from their particular perspective. Many of these institutional predispositions lie with agency staffs. There is a need to break down barriers, to think and work jointly, and to make joint use of facilities. Common ground needs to be found among communities, agencies and businesses.
- Congestion needs to be looked at from a collective institutional viewpoint. All affected jurisdictions should be involved in making the decisions.
- Long range planning offers the opportunity for cross communication and pollination of ideas. Long range regional and statewide plans should provide overall direction. Owner agencies like ADOT should use this direction and work with affected local agencies to decide and implement specific congestion mitigation strategies.
- Outside the metropolitan areas, there is a need to work with statewide agencies such as DPS and AAA. There may be conflicts between local needs, such as small community development goals, and regional and system travel needs.
- Turf issues must be considered. For example, inter-regional travel between MAG and PAG is becoming an issue with those regional agencies. As a result they are beginning to discuss this issue. That could lead to turf issues with CAAG, which is sandwiched between them.
- HOT lanes and congestion pricing are examples of cross-jurisdictional issues that require the involvement of multiple agencies and stakeholders.
- The appropriate lead agency for selecting congestion mitigation strategies depends on the strategy. ADOT might be the lead agency for making ITS decisions on the State Highway System. On the other hand, parking supply or rates are appropriately a local decision, although ADOT could suggest that they be considered.
- The determination of performance standards should be a cooperative process. There should be regional discussion with local input. Performance criteria need to be understandable to all affected agencies and the public.
- Statewide decisions should be needs based as opposed to equity based.
- Other statewide and federal agencies, such as the DEQ, State Land Department, Forest Service and Indian Tribes need to be involved in congestion mitigation strategies that affect their interests.
- Business decisions and practices have a huge impact on congestion. Private/public or public/private congestion mitigation partnerships need to be considered. Carpool/vanpool, staggered work hours and remote work site programs are examples. The private sector has a lot of data that would be of value in making congestion mitigation decisions.
- Intercity transportation carriers should be part of the decision making process.
- Elected officials need to be involved in discussions about congestion mitigation strategies which they will eventually be required to decide on.
- Approaches that could help overcome the institutional cultural problem include staff exchange programs and frequent regularly scheduled meetings or interactions among agencies with common interests (but different viewpoints).

- Small community and Tribal cultures need to be considered in congestion mitigation decisions.
- Numerous perception and communication gaps exist, such as generational gap thinking and territorial gaps involving differing community values. A lot of private sector institutions are not public institution friendly. These gaps need to be bridged to successfully implement some mitigation strategies.
- There is a need to have the ability to access and understand institutional data that affects congestion mitigation strategies.
- Congestion means different things to different people both inside and outside organizations, again pointing to the need to find common ground and understanding.
- ADOT has a role in congestion education and in facilitating, not dictating, congestion solutions.
- Congestion is a local mind-set and needs to be understood from the local perspective.
- The private sector should be held accountable for new congestion and transportation system demands that they create through new or expanded development.

5.4 RECOMMENDED STRATEGIES

From the pool of mitigation strategies in Section 2.8.5, the research study recommends 99 viable and relevant strategies for inclusion in the resource toolbox. Table 5 lists the strategies grouped by category. Of the 99 strategies, nearly half have rural focus. Recommended strategies were chosen after careful consideration of the following factors: the ADOT's performance-based environment in Section 3, the relevant characteristics of Arizona and its State Highway System in Section 5.2, and the application of the database fields described in Section 5.3.

A detailed two-page summary of information pertaining to each of the 99 strategies is presented in Appendix F.

Table 5 Recommended Strategies Grouped by Category

CATEGORY / STRATEGY NUMBER AND NAME			
Access Management			
#1	Driveway Management	#3	Median Management
#2	Frontage Roads		
Advanced Public Transportation Systems			
#4	Automatic Vehicle Location System	#6	Vehicle Management Systems
#5	Electronic Fare Payment		
Advanced Traffic Management Systems			
#7	Alternate Routing Information System	#12	Freeway Management
#8	Automatic Anti-Icing System	#13	Highway-Rail Intersections Management
#9	Electronic Border Crossing	#14	Smart Corridors
#10	Electronic Toll Collection (ETC)	#15	Special Event Plans
#11	Emergency Management		
Advanced Traveler Information Systems			
#16	Dynamic Message Sign	#18	Regional Multimodal Traveler Information
#17	Kiosk	#19	Road Weather Information Systems (RWIS)
Advanced Vehicle Control Systems			
#20	Collision Avoidance System	#21	Vehicle Guidance System
Alternative Work Arrangements			
#22	Compressed Work Weeks	#24	Staggered Work Hours
#23	Flex-Time		
Arterials and Collectors			
#25	Add Lanes to Existing Facilities	#26	Construct New Facilities
Commercial Vehicle Improvements			
#27	Advanced Port Processing Plans	#30	Intermodal Facilities
#28	Commercial Vehicle Facilities	#31	Truck Routes
#29	Geometric Improvements		
Commercial Vehicle Operations (CVO)			
#32	Electronic Credential Checking	#33	Weigh-in-Motion System
Communication Substitution			
#34	Online Shopping	#36	Teleconferencing
#35	Telecommuting	#37	Teleshopping
Construction Management			
#38	Advance Notice	#41	Lane Closures Management
#39	Construction Management Plans	#42	Signing
#40	Detours		
Expressways			
#43	Add Lanes to Existing Facilities	#44	Construct New Facilities
Freeways			
#45	Add Lanes to Freeways	#48	Freeway Express Lanes
#46	Construct New Freeways	#49	Freeway Ramp Lane Additions
#47	Freeway Auxiliary Lanes	#50	Freeway to Freeway Connections

HOV Measures			
#51	HOV Priority Systems	#52	HOV Support Services
Incident Management			
#53	Hazardous Material Incident Response	#56	Incident Information/Routing
#54	Incident Clearance	#57	Incident Response
#55	Incident Detection/Verification		
Land Use/Zoning and Growth Management			
#58	Compact Development	#61	Mixed Use Development
#59	Corridor Land Use and Transportation Coordination	#62	Transit-Oriented Development
#60	Jobs/Housing Balance		
Non-Motorized Measures			
#63	Bike Lanes	#66	Pedestrian Overpass/Underpass
#64	Bike Route Marking/Signing	#67	Shared-Use Paths
#65	Bike/Pedestrian Support Services	#68	Sidewalks
Road Pricing			
#69	Parking Fees	#70	Road User Fees
Roadway Geometric Improvements			
#71	Acceleration/Deceleration Lanes	#78	One-way Couplets
#72	Bus Turnouts	#79	Passing Lanes
#73	Channelization	#80	Providing Additional Lanes without Widening
#74	Climbing Lanes	#81	Reversible Lanes
#75	Grade Separation	#82	Turn Lanes
#76	Improve Shoulders	#83	Vehicle Pullouts
#77	Lane Widening		
Time-of-Day Restrictions			
#84	Parking Restrictions	#86	Turning Restrictions
#85	Truck Restrictions		
Traffic Operational Improvements			
#87	Ramp Metering	#88	Traffic Signal Improvements
Transit Capital Improvements			
#89	Exclusive Right-of-Way Facilities	#91	Transit Support Facilities
#90	Fleet Improvements		
Transit Operational Improvements			
#92	Fare Incentives	#94	Transit Marketing/Information
#93	Traffic Operations for Transit	#95	Transit Service Improvements
Travel Demand Measures			
#96	Guaranteed Ride Home Programs	#98	Ridesharing Programs
#97	Parking/Site Management	#99	Transit/Carpool Incentives

6. RELATIONAL DATABASE IN MS ACCESS

The recommended strategies listed in Table 5 (Section 5.4) are stored in a relational database. A relational database is a powerful system of storing information. It organizes information by way of two-dimensional tables, i.e., with columns or fields of attributes pertinent to rows or records of data. Each table stores one topic or subject and is uniquely identified. Likewise each record in a table must be unique. Tables are logically linked to enable querying of meaningful information. The ability to link tables and dynamically query makes a relational database system efficient in extracting information from a diverse set of data. Figure 3 shows a sample of the information relating to a particular strategy that can be queried from the database.

The relational database system for the strategies toolbox uses MS Access 2002. For the size of the resource toolbox database, MS Access is more than sufficient and is widely available.

The congestion mitigation strategies database in MS Access 2002 has 32 tables and 26 fields (see Figure 2 for the fields defined for each strategy). Of the 26 fields, 16 have "pick list" items or "pull-down" lists. Appendix G provides details for these tables and "pick-list" fields.

6.1 MULTIPLE CHARACTERISTICS

The design of the congestion strategies database allows multiple choices for each field. For example, more than one objective and performance measure can be associated with a strategy. Similarly, a strategy may be applicable to more than one geographic location type or functional class of road. Thus, the database design achieves ADOT's desire to satisfy multi-objective strategies and to meet multiple performance measures.

6.2 EXTRACTING INFORMATION

To facilitate querying of information from the database, various forms were designed, together with user-friendly queries and printable reports. The queries allow users to simply select from the "pull-down" list, and click on a button to preview or print the results. Details of the forms, queries and the reports, and a guide to use the database are provided in Appendix G.

6.3 LINKING THE CONGESTION INDEX AND THE STRATEGIES DATABASE

The fully relational design of the strategies database allows straightforward linking to the proposed congestion index. The two separate databases can be linked, for example through the index threshold values defined for a route or functional class, as well as by location type. The congestion index will be associated with the entire State Highway System. HPMS and other databases can also be linked to the congestion index and the strategies database.

STRATEGY #	3	Median Management	ORIENTATION	Supply
CATEGORY	Access Management			

DESCRIPTION

Median management involves the installation of center medians within a roadway that limit left turning movements as well as cross movements. The removal of left turns and cross traffic increases capacity and improves vehicle throughput and safety along the major roadway. Median management also involves the establishment of median breaks where left turn and through movements are allowed. Bi-directional left turn lanes can also be installed to allow left-turns from the major roadway while restricting through and left-turns from the cross street. Median management is typically facilitated through state or municipal regulatory policies and requirements that are applied to one or more functional classes of roadway. The regulatory requirements detail policies on median placement, median break locations, and median break spacing. Land use/zoning and growth management is a complementary strategy.

Application of this strategy is ideal where access related problems occur or in areas that are being developed to prevent access related issues in the future. Median management is also beneficial in areas with large numbers of accesses that create turning movement conflicts, at roadway sections with too many median breaks, when median breaks adjacent to intersections interfere with the operation of the intersection, at bi-directional turn lanes that are near capacity, and at locations that do not currently have bi-directional turn lanes. Uncontrolled strip development often leads to the need for median management and other access management strategies to restore

INSTITUTIONAL FACTORS

The implementation of median management measures is the responsibility of the agency with jurisdiction over the affected roadway. An agency may have a long standing policy of median management, but may not make significant changes in median configuration unless in conjunction with a roadway improvement. In limited circumstances, businesses have successfully petitioned an agency for reestablishing a median cut, citing adverse conditions and access.

FACILITY CHARACTERISTICS	FUNCTIONAL CLASS	GEOGRAPHIC LOCATION	CONGESTION TYPE	CONGESTION PERIOD
Frequency of Access Points	Principal Arterial Other	All locations	All congestion types	All Day
Number of Lanes	Minor Arterial			All Year
	Major Collector			

PERFORMANCE OBJECTIVES	PERFORMANCE MEASURES	DATA REQUIREMENTS
Improve Safety	Accident rates	Accident rates
Improve Travel Speeds	Average speed	Moving car runs
Increase Capacity	Delay on minor street	Traffic counts
Reduce Conflicts	Effects on business	
Reduce Delay	Miles of congested roadway	

SYSTEM BENEFITS	USER BENEFITS	OTHER BENEFITS
Increase capacity	Improve travel speeds	Improve safety
Reduce conflicts	Reduce delay	

DISADVANTAGES

Turning vehicles may experience increased travel distances and times if alternative routing is necessary. The possibility of reduced accessibility to adjacent properties is also a concern.

RELATIVE BENEFITS

Medium

RELATIVE COST

Medium

EASE OF DEPLOYMENT

Medium

EXAMPLES

A study in Wichita, Kansas, reported that prohibition of turns between intersections by use of a median reduced accidents between intersections by amounts ranging from 43 percent to 69 percent during the first three years after the median was installed. During the same period, accidents at intersections where turns were not prohibited increased by amounts ranging from 12 percent to 38 percent. However, because accidents between intersections originally represented more than 60 percent of the total accidents on the street section affected by the construction, the median construction resulted in a net accident reduction ranging from 12 percent to 38 percent (see section on Arterial Access Management).

Figure 3 Sample Database Form Showing Strategy Attributes

7. SUMMARY AND RECOMMENDATIONS

7.1 SUMMARY

The primary objective of the **Congestion Mitigation Resources and Strategies for Arizona's State Highway System** research effort was to identify a variety of practical planning tools and mitigation strategies that can be used to help anticipate, detect and solve congestion problems in Arizona's 6,200-mile State Highway System. A key factor in the long-term success of this statewide effort is building consensus among Arizona's transportation stakeholders on the issue of congestion including its definition and methods of measurement. At the conceptual stage of the project, the TAC recognized the need to carry out the research in phases. The scope was developed as a comprehensive three-phase work plan. Phase I was to assess the current congestion mitigation practices in the state of Arizona. This identification stage involved a thorough baseline study of Arizona's current state, regional and local congestion mitigation practices, policies, measurements, and systems, as well as any ongoing congestion mitigation planning efforts. Two tasks were specifically designed to achieve the objectives of this phase: (1) Conduct an agency survey to review current agency practices; and (2) Review the current State Transportation Plan and related studies within the State of Arizona. Phase II was focused on congestion itself. Two major objectives of this phase were to arrive at an acceptable definition of congestion on Arizona's highways and to analyze the methods of measuring congestion and its impacts. Three tasks were specifically designed to achieve the objectives of this phase: (1) Comprehensive review of literature; (2) Survey of agencies, transportation professionals and researchers on a nationwide basis; and (3) Regional conference and workshop. Phase III was focused on the development of a toolbox of congestion mitigation solutions most suitable for implementation in Arizona.

Under Phase I, the findings of the Arizona agencies surveyed provided a good background and resource in the development of the congestion mitigation strategies toolbox. Review of the State Transportation Plan and related studies provided a useful guide and input in the selection of appropriate congestion mitigation strategies.

Under Phase II, the comprehensive literature review yielded: (1) criteria for performance measurement; (2) techniques to collect or estimate congestion data; (3) strategies to mitigate and/or manage congestion; and (4) evaluation procedures. The nationwide survey indicates that Arizona is in a similar situation to its partner states throughout the country in striving to manage congestion, incorporate performance based measures, and attempting to tie congestion monitoring to planning and programming. The regional conference and workshop yielded considerable insight with emphasis on Arizona-specific issues.

Under Phase III, based on the work performed in Phases I and II, a toolbox consisting of a congestion index and a mitigation strategies database was developed.

The research project has produced recommendations for systematically quantifying congestion on Arizona's highways using a state-specific congestion index, and has also produced a database of available congestion mitigation strategies in Microsoft Access. Sections 7.2 and 7.3 outline the research recommendations. The Arizona congestion index and mitigation strategies database are the primary elements of the emerging ADOT congestion mitigation toolbox. ADOT is planning for a pilot implementation of the resource toolbox in preparation for statewide deployment.

7.2 CONGESTION MITIGATION STRATEGIES RECOMMENDATIONS

The congestion mitigation strategies database created as part of this toolbox was prepared for specific application to Arizona's highways. This research project recommends:

- Use of the 99 strategies identified in Table 5 and Appendix F to mitigate congestion on the state highway system.
- Utilize the database to identify applicable strategies for various functional class, facility, location, congestion period and congestion types.
- Use of the strategies database to identify strategies that will achieve specific performance objectives and benefits.
- Use the database to identify institutional issues, warrants, relative costs, system benefits, user benefits, other benefits, performance measures, data requirements, ease of deployment, disadvantages, implementation examples, and the effects associated with evaluation of individual strategies.
- Apply the strategies database at the planning level for determining feasible congestion mitigation strategies, estimating costs of congestion mitigation at the system level, establishing long range priorities for congestion mitigation, and assigning congestion mitigation benefits to alternative long range transportation plan strategies.
- Implement the strategies database at the programming level to incorporate congestion mitigation into specific projects that are programmed in the near future in order to address concerns and meet goals in specific locations of the State, to estimate the cost of mitigating to specific index levels, to determine the congestion mitigation priorities for specific levels of mitigation funding, and to assign congestion mitigation benefits to alternative program strategies.
- Apply the strategies database at the project level to implement specific strategies and to assess the costs and benefits for incorporating these strategies into projects.
- Use of the database by local and regional planning agencies in Arizona and elsewhere in developing congestion mitigation solutions at the project, programming and planning levels.

7.3 PROPOSED CONGESTION INDEX RECOMMENDATIONS

Chapter 4 of this report outlines the congestion index that is proposed for the Arizona Department of Transportation's resource toolbox that could be implemented for the 6,200-mile State Highway System in Arizona. The research team recommends both strategic and short-term planning approaches for congestion monitoring on Arizona state highways.

7.3.1 Strategic Recommendations

- Use the Travel Time Index as the Key Measure of Congestion.

  As its key congestion measure, ADOT should use the travel time index, which is defined as the ratio of peak period travel time to free-flow travel times. The travel time index may need to be adjusted or weighted to be sensitive to rural congestion concerns, but more work is needed to confirm the best approach. In addition to this key measure, the project team recommends several other travel time-based measures that quantify different dimensions of congestion. These other measures include delay per traveler (minutes per person), percentage of travel that is congested (i.e., vehicle, person, or freight ton-miles of travel), and the buffer time index (i.e., a measure of travel time reliability). These concepts are summarized here but documented fully at the Texas Transportation Institute web link at http://mobility.tamu.edu.

- Utilize Existing Data and Information Systems to Estimate Congestion.

  The recommended short-term approach for congestion monitoring on Arizona state highways should rely on three primary sources of data to estimate both recurring congestion (where travel demand regularly exceeds available roadway capacity) and non-recurring congestion (where planned or unplanned "events" either disrupt smooth traffic flow or exacerbate regular traffic problems). These three primary sources of data are: (1) archived operations (or ITS) data from traffic operations centers or arterial street signal systems; (2) ADOT's Highway Closure and Restriction System (HCRS) that is currently used to report special conditions or events on Arizona's state highways; and (3) ADOT Transportation Planning Division's (TPD) highway traffic database that is currently used to estimate congestion (via level of service measures) on a statewide basis. All three of these recommended resources will require work and expense to fully develop and integrate their capabilities as required for calculation of the travel time index.

- Recognize that the Congestion Monitoring Process will Evolve Over the Next Five to Ten Years.

  ADOT should recognize that the congestion data sources and estimation procedures would evolve and improve over time. For example, operations-based traffic sensors will continue to be deployed in efforts to manage congested traffic and provide traveler information. Although operations sensors currently cover less than two percent of state highway mileage, it includes about 25 percent of the state's total vehicle-miles of travel (VMT) and an even greater portion of the congestion. The data from these operations sensors can also be used to improve and validate the travel time estimation procedures in the HCRS and TPD databases. The benefits will come from improved archived operations data, and enhanced congestion estimation procedures in the HCRS and TPD databases.

- Develop "Mobility Targets" (i.e., Acceptable Congestion Standards) Based on Location, Functional Classification, and/or Route Level of Development.

  The travel time index compares peak period travel times to free-flow travel times. In some cases, however, free-flow travel times may not be possible or desirable given local growth patterns, funding and environmental constraints, and public/political support. Thus, ADOT should develop "mobility targets" that define the acceptable travel time index values (analogous to defining an acceptable level of service). Initial mobility targets can be established by benchmarking existing congestion levels and then setting appropriate but realistic targets given policy goals and existing conditions. Input to the mobility targets can also be obtained during transportation plan updates.

- Use Mobility Targets to Differentiate between Acceptable Urban and Rural Congestion.

  It is envisioned that the mobility targets will be one of the mechanisms that is used to equitably distribute congestion mitigation funds between the urban and rural areas of the state. This can be accomplished by setting "higher" mobility targets in rural areas than in urban areas. For example, the mobility target for rural areas could be a travel time index value of 1.00 (free-flow travel), whereas the mobility target for urban areas could be a travel time index value of 1.20 (peak period travel times 20 percent higher than free-flow). Thus, congestion mitigation “triggers” would occur at higher speeds on rural roadways than urban roadways.

- Periodically Examine and Update Mobility Targets Based Upon Congestion Benchmarks and Customer Satisfaction.

  The initial mobility targets could be developed by calculating existing congestion (e.g., benchmarking), then setting appropriate but realistic mobility targets. Data from customer satisfaction surveys can also serve as a critical indicator of acceptable congestion levels. Once developed through a congestion benchmarking process, these mobility targets could be updated to reflect changing customer expectations and preferences. Thus, we recommend that customer satisfaction surveys be a part of the ongoing congestion monitoring process.

- Consider a Pilot Project and/or Phased Implementation as a Means to Fully Develop the Congestion Monitoring and Mitigation Program.

  A pilot project could be used to test the application of the recommended congestion measures, data estimation techniques, and mitigation strategies. A pilot project would also help move this project’s recommendations a step closer to implementation within ADOT.

7.3.2 Short-Term Implementation Recommendations

The recommended short-term approach for congestion monitoring on Arizona state highways should rely on three primary sources of data to estimate both recurring congestion (where travel demand regularly exceeds available roadway capacity) and non-recurring congestion (where planned or unplanned "events" either disrupt smooth traffic flow or exacerbate regular traffic problems). These three primary sources of data and how they contribute to the "Arizona congestion picture" are as follows:

- Archived Operations (or ITS) Data.

  Archived operations data should be used to directly measure roadway congestion in large metropolitan areas where ITS has been deployed. Archived operations data typically consist of traffic volume and speed data on major freeways and some arterial streets in large metropolitan areas, and are collected continuously (24 hours a day, 365 days per year) in detailed time (5 minutes or less) and space (1 mile or less) intervals. The archived operations data serves as one of the best measurements of congestion where it is available, and this data source is being pursued widely by numerous DOTs for congestion/performance monitoring. Two major advantages are that (1) this data source covers many of the most congested state highways in Arizona, and (2) the data source captures both recurring and non-recurring congestion. A major limitation is that operations sensors currently cover less than 5 percent of the total statewide highway system. There are also issues of comparability between direct measurements of congestion (as with archived operations data) and congestion estimates from other empirical processes such as those described in the following two primary data sources below.

- Highway Closure and Restriction System.

  The HCRS database should be used to estimate non-recurring congestion that occurs on state highways with no operations sensor coverage (the principal majority of Arizona's state highway system). The HCRS database currently captures a wide variety of events that produce traffic congestion outside of major metropolitan areas, such as work zones, incidents, and weather events. Non-recurring congestion will be estimated by traffic models using data entered into HCRS by ADOT district personnel and other local government entities. The traffic models will utilize HCRS data such as location and length of event (milepost-based), number of lanes closed/affected, estimated duration of event, and other data necessary to compute travel times and delays using traffic flow models. The traffic models to estimate non-recurring congestion may also require baseline traffic conditions and roadway geometry, which is available in transportation planning databases (see next item below). Major advantages of using HCRS to estimate non-recurring congestion are (1) the database is already in place and has widespread acceptance and use throughout Arizona and (2) it enables an estimate for non-recurring congestion, which may be a large portion of the total congestion picture on many state highways. A limitation is that the congestion is only an estimate, and not a direct measurement of congestion.

- Transportation Planning Division (TPD) Traffic Database.

  The ADOT TPD traffic database, which consists of planning-level roadway traffic and geometry data, should be used to estimate recurring congestion on state highways with no operations sensor coverage. TPD currently uses this same database to generate statewide roadway level of service (LOS) estimates. For numerous reasons described previously, the project team recommends that ADOT migrate from LOS-based congestion measures to travel time-based congestion measures. The same underlying TPD database, though, can be used to estimate the travel time-based congestion measures. Various travel time estimation procedures from planning-level data have already been developed for other applications; however, it will be necessary to adapt and validate these estimation procedures for Arizona state highways. A major advantage of using the TPD database is that this same database is already being used to generate statewide congestion estimates, albeit congestion via LOS measures. A limitation is that the congestion is only an estimate, and not a direct measurement of congestion.

If ADOT pursues this short-term approach of utilizing three existing databases, the primary implementation challenge will be integrating data from the three "legacy" systems. All three of these recommended resources will require work and expense to fully develop and integrate their capabilities as required for the recommended congestion index concept.

As has been described previously, the recommended long-term approach for congestion monitoring in Arizona includes travel time and speed sensor deployment along Arizona's key strategic state highways. These sensors could logically be used for multiple purposes beyond congestion monitoring, such as traveler information, traffic control, or incident management.

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APPENDIXES

APPENDIX A

AGENCY AND NATIONAL INDUSTRY SURVEY QUESTIONNAIRE

Agency and National-Industry Survey Questionnaire

Name: ______________________________

Agency: ______________________________

Q_1 How big an issue is congestion in your jurisdiction?

____
____
____

Q_2 Where does congestion mitigation stand on your jurisdiction's priority list?

____
____
____

Q_3 What do your customers think about congestion? Has your agency ever done surveys or data collection to determine what congestion levels are acceptable?

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____
____
____

Q_4 How does your agency define congestion? Does the definition distinguish between rural and urban congestion?

____
____
____
____

Q_5 How do you measure congestion? Does this differ between rural and urban areas of your jurisdiction? What are the congestion issues for rural and urban areas?

____
____
____
____
____

Q_6 At what point does the system breakdown and congestion start (threshold)?

____
____
____
____

Q_7 Has your jurisdiction conducted a study related to congestion? If so, have you identified the costs (effects) of congestion?

____
____
____

Q_8 Has your agency ever collected data relating to congestion? If so, what kind of data and was it worthwhile?

Q_9 How do you evaluate and select any congestion mitigation measures? Is this done on a project-by-project basis?

Q_{10} What are valid performance measures for evaluating congestion mitigation strategies?

Q_{11} What is your agency currently doing or planning to do about congestion? Do you have a congestion monitoring or management program?

Q_{12} Is congestion inevitable?

Q_{13} Can we "build our way out" of congestion?

Q_{14} How can we utilize the suggestions of ongoing air quality, energy conservation, and land use planning studies in Arizona to mitigate congestion?

Other Suggestions/Recommendations:

APPENDIX B

ARIZONA TRANSPORTATION STUDIES REVIEWED

Arizona Transportation Studies Reviewed

State Transportation Plan (ADOT-TPD)

Arizona State Transportation Plan, December, 1994

Arizona Statewide Studies (ADOT)

Arizona Congestion Management System, 1996
Intermodal Management System, 1995
Arizona Port Efficiency Study, 1997
Status & Condition of the Arizona Highway System, 1999
Arizona Transportation Needs Assessment, 1995
Highway Level of Development Study, 2000
Strategic Plan for Statewide Deployment of Intelligent Transportation Systems in Arizona, 1998
Vision 21 Task Force Report

ADOT Corridor Profile Studies (ADOT)

US93 - Beardsley Canal to Nevada State Line, 1996
US 160 - Jct US 89 to Four Corners, 2000
I-10/B-10 - California State Line to Oglesby Road/SS 85 and B-10 in Quartzsite, 1998
SR 82, 90, and 92 - Cochise county, 1990
US 95 - Yuma to Yuma proving grounds, 1989
US 60 and SR 88 - Apache Jct to US 70 and Apache Jct to Claypool, 1988
US 89, 89L, 89A and SR 389, 67, 1988
US 60 - County Line to US 70, 1998
SR 89 - South of Prescott, 1997
SR 260, US 60, SR 77, and SR 277, 1985
SR 87 and 260 - Fountain Hills to Payson and Payson to Pinetop, 1997
SR 80, 90, and 92 - southeast AZ, 1998
San Luis-Bullhead City Multimodal Corridor (US/SR 95, SR 68, and SR 72) - 1997
SR 64 - Williams to Cameron, 1999
Phoenix-Flagstaff-Page Corridor - 1998
US 60 - Show Low to New Mexico, 1999
Tucson-Globe-Holbrook - 1998
I-17/I-10 - 1986 & I-17/I-10 Executive Summary - 1987
US 191 - Springerville to US 160
I-40 - 1999, Exec Summary and Business Route Inventory
I-15 - 1998
I-8, B-8, SR-280 - 1998-Final, 1997-Phase 1
I-8 and US 95 - 1988
SR 86, 286, 386 - 1999
I-19 - Tucson to Nogales, 1996
SR 69, 89, 89A - 1997
Phoenix to Tucson - 1999
I-10 - Tucson to New Mexico State Line, 1998
SR 80 - Douglas to New Mexico, 1999
SR 88, 188 - 2000
SR 85 - Lukeville to Phoenix, 1998

Small Area Studies

Pima Association of Governments Mobility Management Plan Update, 2000 (PAG)

1998 MAG Regional Congestion Study, 2000 (MAG)

MAG Congestion Management System, 1995 (MAG)

MAG Congestion Management Systems Alternatives, 1994 (MAG)

MAG Fixed Guideway System Study, 1999 (MAG)

Traffic Quality on the MAG Regional Freeway System, 2001 (MAG)

Central Yavapai County Transportation Study, 1995 (Yavapai County, NACOG, ADOT)

Central Yavapai County Transportation Study Update, 1998 (Yavapai County, NACOG, ADOT)

PAG Regional Transportation Plan (PAG)

Graham County Transportation Study for the Gila Valley Region, 1992 (Graham County, ADOT)

Cottonwood Area Transportation Plan, 1987 (Town of Cottonwood)

Salt River Pima-Maricopa Indian Community Transportation Planning Study, 2001

Kingman Area Transportation Study, 1997 (City of Kingman, ADOT)

White Mountain Regional Transportation Plan, 1999 (Navajo County, Apache County, ADOT)

PAG Metropolitan Transportation Plan, 1998 (PAG)

MAG Long Range Transportation Plan, 2001 (MAG)

Flagstaff MPO Regional Long Range Transportation Plan, 1999 (Flagstaff MPO, ADOT)

Other State & Federal Studies

Washington State Highway System Plan, 1999-2018, 1998 (Washington State DOT)

Maine's Long Range Transportation Plan 1998-2018, 1998 (Maine DOT)

Arkansas Statewide Long-Range Intermodal Transportation Plan (Arkansas State Highway and Transportation Dept.)

Accessing the Future, The Intermodal Transportation Plan for the Commonwealth of Massachusetts, 1995 (Massachusetts Highway Department)

Congestion Management System - Nashville Area MPO, 1995

Ferguson, E., "Three Faces of Eve: How Engineers, Economists, and Planners Variously View Congestion Control, Demand Management, and Mobility Enhancement Strategies," Journal of Transportation and Statistics, 2001

Reno, A. T., "Personal Mobility in the United States," A Look Ahead: Year 2020, (Proceedings of the Conference on Long Range Trends & Requirements for the Nation's Highway & Public Transit System) (Transportation Research Board, National Research Council)

Western Transportation Trade Network (WTTN), 1997

Iowa in Motion: State Transportation Plan, 1997 (Iowa DOT)

Kansas Long-Range Transportation Plan, 1995 (Kansas DOT)

A Survey of Transportation Planning Practices in State Departments of Transportation (Virginia Transportation Research Council)

Virginia Statewide Intermodal Long-Range Transportation Policy Plan, 1995 (Virginia DOT, Virginia Port Authority)

APPENDIX C

REVIEW OF CURRENT LITERATURE OF CONGESTION MITIGATION RESEARCH AND PRACTICES IN THE UNITED STATES

Review of Current Literature of Congestion Mitigation Research and Practices in the United States

Executive Summary

The review of current literature was performed as part of the Arizona Department of Transportation's Congestion Mitigation Resources and Strategies for Arizona's State Highway System research project. The project's primary objective is to identify practical planning tools and mitigations strategies that can be used to help anticipate, detect and solve congestion problems on the Arizona State Highway System as they arise. The literature review reveals current measurements, technologies, and strategies being implemented to measure, monitor, and mitigate congestion in the United States, excluding Arizona.

<u>Metrics</u>

Measurement of congestion is critical in assessing the current status of congestion and the level of benefit derived by implementation of mitigation strategies. The Highway Capacity Manual methods of measurement are probably the most widely used in the United States. This literature review documents HCM applications and limitations, including the 1998 MAG Regional Congestion Study's use of HCM methodologies. The Seattle Metropolitan Freeway System is cited in this review for their application of performance measures to assess system performance, site specific performance, and HOV performance. The literature review details performance measures from the before and after comparative Twin Cities Ramp Meter Evaluation by the Minnesota DOT. Finally, the review gives comprehensive documentation of the findings from NCHRP Report 398, Quantifying Congestion, Volume 1.

<u>Technologies</u>

This section of the literature review reveals technologies that are being used to collect congestion data. The role of ITS in data collection and in optimizing the efficiency of transportation systems is a valuable resource for congestion mitigation. This review presents existing sensor technologies and data requirements for ITS from various sources. The review highlights information from an FHWA study that provides current information on the theory and specification of non-intrusive sensors; recent findings on traffic management tactics, algorithm descriptions and performance; and data requirements for various ITS strategies. The review documents current literature on real-time congestion detection. These sources relate current practices of freeway and surface street incident detection, and adaptive traffic control systems. The review also reports the findings of NCHRP Report 398, Quantifying Congestion, Volume 2, User's Guide. The methodologies from Volume 1 of this report use measures which rely heavily on travel

time and vehicle occupancy data. This review highlights findings from the NCHRP report and other sources which address approaches that can be taken to collect this data.

Strategies

A search through current literature documenting congestion mitigation strategies revealed generally the same strategies. Four principal sources were used to develop a representative list of current strategies and include:

- Houston's 2000 Travel Rate Improvement Program (Greater Houston Partnership, circa 2001).
- A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility (Meyer, 1997)
- Mid-America Regional Council (MARC) Enhanced Congestion Management System (Cambridge Systematics, Inc., Dec. 2001, March 2001, Nov. 2000, and Jan. 2000).
- Handbook of Selected Congestion Mitigation Techniques in the United States (Crawford, et al., 1998)

Each of these sources is thoroughly detailed within this review to relate the application of congestion mitigation strategies by the agency or author. The text addresses funding and includes implementation examples within the jurisdiction and throughout the United States. Strategies in the Houston area were directed to build more capacity, manage demand, increase system efficiency, and change the urban scheme. A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility provides a descriptive and definitive multimodal strategy approach to enhance mobility and accessibility. MARC's Congestion Management System defines a congestion approach through the development of performance measures, a data collection and monitoring program, congestion management strategies, and evaluation procedures for these strategies. This review presents the MARC toolbox of strategies, relates the types of performance measures used and highlights other key aspects of the CMS. The Handbook of Selected Mitigation Techniques in the United States enumerates the cost and impacts of various key congestion strategies for various locations throughout the country.

Research Recommendations

- Develop criteria for performance measure (congestion index)
- Identify techniques to collect congestion data or estimate
- Develop strategies to mitigate and/or manage congestion in the State of Arizona
- Develop evaluation procedures.

Introduction

Arizona's population growth continues to task the State's transportation facilities at a rate exceeding available capacity, resulting into continuously increasing congestion, particularly in the Maricopa and Pima Counties but also in and around Flagstaff, Yuma and along certain rural portions of the interstate corridors. As congestion on State's rural and urban highways is expected to worsen with time, more focus must be directed towards developing tools to help Arizona Department of Transportation (ADOT) and other public agencies in measuring, predicting, and remedying those congestion problems.

ADOT, has initiated a project "Congestion Mitigation Resources and Strategies for Arizona's State Highway System" (Research Project SPR 542 – TRACS No. R0542 12P), with a primary objective to identify practical planning tools and mitigation strategies that can be used to help anticipate, detect and solve congestion problems on State Highway System as they arise. The development of these strategies must consider the variety of technology resources that are now or soon become available to the transportation profession. A key factor in the success of this statewide effort is building consensus among the stakeholders on the issue of congestion including its definition and methods of measurement and resolution. The study will develop a baseline assessment of congestion and congestion management in the state and will then look to the practical experience in the United States to help synthesize an appropriate mix of strategies for the State of Arizona.

Purpose of Literature Search

This literature search is but one of the 17 tasks of the Arizona Department of Transportation's Research Project SPR 542 – TRACS No. R0542 14P, *Congestion Mitigation Resources and Strategies for Arizona's State Highway System*. The project's primary objective is to identify practical planning tools and mitigations strategies that can be used to help anticipate, detect and solve congestion problems on the Arizona State Highway System as they arise. The scope of this literature search is limited to the conduct of a systematic review of current transportation literature in order to identify congestion mitigation research practices in other parts of the country. While this review is reasonably representative of the current literature in the field, it is not exhaustive since its scope and budget were limited by the project resource constraints.

Organization of Information: Metrics, Technologies, and Strategies

A search of technical literature provides considerable information relevant to congestion management that is applicable to Arizona. As used here, congestion management means the tools that are available or emerging that will help ADOT and other Arizona public agencies measure, predict, and remedy traffic congestion problems on the State's transportation facilities. However, what is meant by "congestion" is not as straightforward as might first be assumed. In fact, how to actually define congestion is itself a part of this literature search.

The information from the literature search reported here can be organized in several ways. All organization schemes are artificial to some degree but are used to aid presentation and comprehension. Here the information that was gathered is loosely subdivided into three topics--metrics, technologies, and strategies—and are presented in this order. The logic of the order is that first one must define a subject before one can discuss it. Next the technologies are discussed because most of these have only recently been applied to the transportation field, i.e., within the last 15 years and often within the last 7 years. These two topics--metrics and technologies--lay the groundwork to discuss the strategies employed to "remedy" congestion problems. But be advised that in today's world we are actually discussing ways to mitigate or reduce congestion, realizing full well that a true remedy is usually beyond the resources available.

Today's electronic abstract databases and electronic library transfers allow a thorough literature search to be done in less time than when such resources were not available. While enumeration of the number of references reviewed was not done, estimates were kept. Approximately 500 references were selected for abstract review. Of these, approximately 100 abstracts were of sufficient interest to merit further investigation. Sometimes a reference would be eliminated based on its abstract because a newer reference contained the same or updated data. Several were discarded because they were simply outdated given the rapid changes in the field the last few years. Typically, if the reference was a technical paper deemed potentially relevant, an electronic copy was obtained. This group of references was ultimately reduced to approximately 25 for inclusion in this literature review.

In addition to electronically gathered abstracts, several "thicker" publications were supplied by the Texas Transportation Institute. In addition, other "thicker" publications were ordered from such sources as the Institute of Transportation Engineers and the Transportation Research Board, National Research Council. These types of publications were typically found during the electronic search, but electronic copies were unavailable. Approximately 10 references were ultimately used from this category, while approximately 25 were reviewed. A last source for documents was the World Wide Web. It is becoming more common for local, state, and federal agencies to publish reports and documents on the web. Approximately 5 sources used in this review were drawn from the web, while approximately 50 were reviewed.

This literature review reflects the judgment of the authors. Judgment is always a factor in sifting references and deciding what to include and what to exclude. The guiding principles were significance to the specific topics at hand (relevance), broad coverage of the subject when taken as a whole (comprehensiveness) and, because of the rapidly changing nature of the subject, a bias for later rather than earlier publication dates (contemporary). In final form, this review cites approximately 40 references and presents their findings in varying levels of detail. The references were gathered between December 2001 and May 2002.

METRICS: How Do We Measure Congestion?

One source (Litman, 2001) defines *traffic congestion* as "the incremental costs resulting from interference among road users." While this definition suggests a continuum, the "incremental costs" are left rather open-ended. This section attempts to summarize the major metrics of congestion that were found in the literature. The literature searched was limited to that published within about the last ten years. Each subsection presents a primary set of metrics that are either a unique source or representative of a type. The metrics selected for presentation here are limited to ones that have been used by transportation agencies and found to be useful.

Highway Capacity Manual Methods for All Facility Types

The traditional standard for traffic engineering studies for most federal, state, and local agencies is the *Highway Capacity Manual (HCM)* (TRB, 2000). The first edition of the HCM was published in 1950 with the second edition following in 1965. The third edition in 1985 was arguably the most research-based edition and contained 14 chapters. It was updated in 1994 and 1997 in response to continuing research findings. This third edition and its updates have probably had the greatest impact on the current practices of federal, state, and local agencies regarding the definition and measurement of congestion. The 1994 update impacted fully 8 of the 14 chapters and the 1997 update impacted 9 of the chapters. These updates redefined *capacity* and *Level of Service (LOS)* for both freeways and signalized intersections.

The fourth and current edition of the HCM was issued in 2000 and is often called "HCM 2000". This edition introduces many revised or expanded procedures for calculating *capacity* and *level of service* and provides these useful definitions:

- *Capacity*: the capacity of a facility is the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions.
- *Performance Measures*: each facility type that has a defined method of assessing capacity and level of service [in the HCM 2000] also has performance measures that reflect the operating conditions of a facility, given a set of roadway, traffic, and control conditions. For each facility type, one or more of the stated performance measures serves as the primary determinate of level of service. This LOS-determining parameter is called the service measure or sometimes the measure of effectiveness (MOE) for each facility type.
- *Level of Service (LOS)* is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.

Thus by definition, LOS is based on different service measures for different facility types. In the HCM 2000, LOS is based on:

(1) travel speed for *urban streets*,

(2) control delay for *signalized intersections*,

(3) control delay for *stop controlled intersections* (for each minor movement),

(4) space (the inverse of density) for *pedestrian walkways and sidewalks*,

(5) number of passing and opposing events for *exclusive and shared bicycle paths*,

(6) control delay for bicycles at *signalized intersections* (per movement),

(7) bicycle travel speed for *bicycle lanes on urban streets*,

(8) percent time-spent-following and travel speed for Class I (high speed) *two-lane highways* but only percent time-spent-following for Class II (lower speed) two-lane highways,

(9) density for *uninterrupted multilane highways*, and

(10) density for *basic* and *ramp merge/diverge freeway segments* and speed for *weaving freeway segments*.

It is important to note that the HCM 2000 methodologies often do not apply to oversaturated conditions, i.e., during congestion. The HCM 2000 does not specifically define *congestion* but instead leaves it to the analyst to determine what levels of service are acceptable and unacceptable for the application being considered.

1998 MAG Regional Congestion Study

While not a source from outside Arizona, the *1998 MAG Regional Congestion Study* (Traffic Research & Analysis, Inc., et al., 2000) is reported here because it is archetypal of metrics relying primarily on HCM methods. The study used the 1995 Update of the third edition of the HCM to define LOS for the major intersections and freeway segments within their study area, i.e., greater metropolitan Phoenix. The authors of this study state:

> "Intersections and freeway segments operating at LOS A through C are usually considered to be operating 'under capacity.' LOS D is considered 'near capacity,' and LOS E and F are considered 'over capacity.' LOS E and F indicate levels of traffic congestion and delay that are generally unacceptable to most drivers in major metropolitan areas."

Results were presented graphically in the study, although the detailed data and analysis are available for use by analysts doing microscale investigations. The freeway "segments" defined in the study are simply continuous pieces of the freeway facility, not the *basic*, *ramp merge/diverge*, and *weaving* segments defined in the HCM. The study segments typically begin and end at intersections, defined as the centerline of each overpass or underpass and were usually about one mile in length. Therefore each study segment could, and typically did, contain two or more of the HCM defined segment types.

The MAG study used six performance measures for freeways, all of which can be viewed and interpreted graphically. The primary graphics are presented in a plan view for the general purpose (GP) lanes of the entire study area:

(a) *vehicle volumes*, for segments on weekdays by volume level bins with supplemental digital values indicated alongside segments; three volumes are shown: two-way, 24-hour volumes; AM peak hour volumes; and PM peak hour volumes,

(b) *24-hour truck volumes*, for two-way segments on weekdays by volume level bins,

(c) *AM peak period LOS*, for one-way segments on weekdays,

(d) *AM peak period duration of LOS F*, for one-way segments on weekdays,

(e) *PM peak period LOS*, for one-way segments on weekdays, and

(f) *PM peak period duration of LOS F*, for one-way segments on weekdays,

It is important to note that LOS was shown in four groupings: LOS A, LOS B or C, LOS D or E, and LOS F, i.e., LOS B and C are combined. Duration was shown in four half-hour increments. While not specifically stated, it is assumed since several segments are not shown that these have less than 30 minutes durations, which infers that the increment values shown in the legend (0.5, 1.0, 1.5, and 2.0 hours) are the lower limit of their half-hour increment.

The MAG study used four performance measures for <u>HOV usage</u>, both of which can be viewed and interpreted graphically. The primary graphics are presented in a plan view for of the entire study area:

(a) *AM peak hour HOV lane volumes*, for one-way segments on weekdays by volume level bins with supplemental digital values indicated alongside segments,

(b) *AM peak period HOV lane LOS*, for one-way segments on weekdays,

(c) *PM peak hour HOV lane volumes*, for one-way segments on weekdays by volume level bins with supplemental digital values indicated alongside segments,

(d) *PM peak period HOV lane LOS*, for one-way segments on weekdays, and

The MAG study used six performance measures for major <u>intersections</u>, all of which can be viewed and interpreted graphically. The primary graphics are presented in a plan view, which shows each intersection for of the entire study area:

(a) *AM peak hour LOS,*

(b) *AM peak period duration of LOS F,* with two duration bins of 15-59 minutes and 60 minutes or more,

(c) *AM peak hour temporal location,* where temporal location is one of five hours, incremented at 15 minute intervals, from 7:00 am to 8:00 am,

(d) *PM peak hour LOS,*

(e) *PM peak period duration of LOS F,* with two duration bins of 15-59 minutes and 60 minutes or more, and

(f) *PM peak hour temporal location,* where temporal location is one of five hours, incremented at 15 minute intervals, from 4:00 pm to 5:00 pm.

It is important to note that LOS was shown in five groupings: LOS A or B, LOS C, LOS D, LOS E, and LOS F.

Performance Measures for the Seattle Metropolitan Freeway System

In the Seattle metropolitan area, a freeway usage and performance report was prepared that presented an overview of the level of traveler usage and travel performance on the principal urban freeways in the central Puget Sound area. The work was conducted by Ishimaru, Hallenbeck, and Nee from the University of Washington's Washington State Transportation Center (TRAC) (Ishimaru, et al., 2001; Hallenbeck, et al., 2001; and Ishimaru, et al., 1999). The work was a 1999 update that reported current conditions as well as trends.

The TRAC researchers used five performance measures for freeway corridors, all of which can be viewed and interpreted graphically:

(1) *traffic congestion levels* at locations along the corridor by time of weekday, averaged from data for the entire year,

(2) *congestion frequency* defined as the likelihood that significantly congested traffic will occur at a particular location and time of weekday, averaged from data for the entire year,

(3) *average trip travel times* estimated for 18 hypothetical trips (9 routes, traveling in both directions) that traverse one or more corridors, for a range of trip start times throughout a 24-hour weekday, averaged from data for the entire year.

(4) *90th percentile travel times* (i.e., 90% of time travel would take less than this time) estimated for the same 18 hypothetical trips and start times as used for average trip travel times [the difference between the average trip time and the 90th percentile trip time can be thought of as an indicator of variability or reliability for the trip], and

(5) *frequency of "slow" trips* estimated the percentage of times that the average overall trip speed for the 18 hypothetical trips would be below 35 mph for a given start time.

While the corridor performance measures give an overview of system performance, the TRAC researchers used three different performance measures to evaluate performance at specific sites. These three measures can be plotted on the same chart and interpreted graphically:

(1) *average traffic volume* at the site by time of weekday, averaged from data for the entire year,

(2) *average speed* at the site by time of weekday, averaged from data for the entire year, and

(3) *frequency of heavy congestion* at the site measured as the percent of time that congestion will be encountered at a time of weekday, averaged from data for the entire year.

The occupancy requirement for all High Occupancy Vehicle (HOV) lanes on the Seattle metropolitan freeway system is at least 2 occupants, except for the westbound lanes of SR520, which requires 3+ occupants. The TRAC researchers used two performance measures for HOV usage, both of which can be viewed and interpreted graphically:

(1) *number of vehicles* traveling per lane per hour by time of weekday, on both the general purpose (GP) and the HOV lanes, averaged from data for the entire year, and

(2) *number of persons* traveling per lane per hour by time of weekday, on both the GP and HOV lanes, averaged from data for the entire year.

Where needed for these measures, the TRAC researchers defined the threshold of congestion as the transition from traffic condition LOS E to LOS F, based on a freeway freeflow speed of 65 mph, as defined by the Highway Capacity Manual (HCM). However the HCM version date was not referenced. Lane occupancy percentage was used to estimate the LOS transition point. Occupancy assumes a fixed average vehicle length, which introduces some error. Therefore the researchers cautioned that the congestion estimates should be used as comparative and qualitative, rather than as absolute values. The same caution applies to speed estimates.

Twin Cities Ramp Meter Evaluation

The Minnesota state legislature mandated that the Minnesota DOT (Mn/DOT) conduct an evaluation of the freeway ramp metering system in the Twin Cities region. The study was initiated in the fall of 2000 by an independent consultant, Cambridge Systematics (Cambridge Systematics, Inc., 2001). The study was motivated by a questioning of some members of the public as to the effectiveness of the ramp metering strategy employed by Mn/DOT. The legislative bill required Mn/DOT to study the effectiveness of ramp meters in the Twin Cities region by conducting a shut-down study. The goal of the study was to evaluate and report any relevant facts, comparisons, or statistics concerning traffic flow and safety impacts associated with deactivating system ramp meters for a predetermined amount of time. The final report presented this conclusion:

> "1) It [the study] thoroughly documented the benefits resulting from ramp metering to traffic operations and related factors such as air quality in the Twin Cities metro region. Analysis of field data indicates that ramp metering is a cost-effective investment of public funds for the Twin Cities area.
>
> 2) It [the study] demonstrated the need for Mn/DOT to adjust its approach to ramp metering in a way that will optimize benefits while conforming to public expectations. Analysis of market research data shows that a clear majority of users of the Twin Cities metro region highways support continued operation of ramp meters as a congestion management tool in some modified form.
>
> The combination of these two factors point towards the adoption of an overriding principle regarding the operation of ramp meters in the Twin Cities. This principle would seek to 'balance the efficiency of moving as

much traffic during the rush hours as possible, consistent with safety concerns and public consensus regarding queue length at ramp meters."

The study identified evaluation objectives and identified one or more performance measures that would provide an assessment of the objective. Wherever possible, quantitative evaluation measures were used; however many of the measures were deemed to be more appropriately expressed in qualitative terms. The study evaluation objectives and performance measures are presented in Table 1.

Table 1 Twin Cities Ramp Metering Evaluation Objectives and Measures

Evaluation Objective	Performance Measure
1. Quantify ramp metering safety impacts for selected corridors.	• Change in the number of crashes occurring in selected corridors. • Change in the severity of crashes occurring in selected corridors. • Change in the number of traffic conflicts (non-crashes) occurring at specific corridor locations (ramp merge and adjacent intersections). • Change in HOV lane violations. • Perceived change in safety of travel in selected corridors.
2. Quantify ramp metering traffic flow and travel time impacts for selected corridors.	• Change in travel time for primary travel route in selected corridors. • Change in travel time for alternative travel routes in selected corridors. • Change in travel speed for primary travel route in selected corridors. • Change in travel speed for alternative travel routes in selected corridors. • Change in traffic volume for primary travel route in selected corridors. • Change in traffic volume for alternative routes in selected corridors. • Change in travel time reliability for selected corridors. • Change in traffic volume, travel time, travel speed, and travel time reliability for on-ramps in selected corridors. • Perceived change in travel time for selected corridors. • Perceived change in travel time reliability for selected corridors.
3. Extrapolate ramp metering safety impacts to the entire system.	• Change in the number of crashes occurring systemwide. • Change in the severity of crashes occurring systemwide. • Estimated change in the regional crash rate for different facility types. • Estimated regional change in vehicle miles traveled for different facility types. • Estimated change in regional volume to capacity (v/c) ratios. • Perceived change in systemwide safety of travel.
4. Estimate ramp metering impacts/ benefits (positive and negative) on energy consumption and the environment.	• Estimated regional change in emissions by pollutant and by facility type. • Estimated regional change in fuel consumption by facility type.
5. Extrapolate ramp metering traffic flow impacts/benefits (positive and negative) for the entire system.	Estimated regional change in travel time. Estimated regional change in vehicle miles traveled for different facility types. Estimated regional change in travel speed for different facility types. Estimated regional change in travel time reliability. Perceived regional change in travel time. Perceived regional change in travel time reliability.
6. Compare the systemwide ramp metering benefits with the associated impacts and costs.	Change in the number and severity of crashes occurring systemwide. Change in systemwide travel times. Change in the total number of trips. Change in travel time reliability. Change in fuel use and other user paid costs. Change in vehicle emissions levels.

	Estimated change in DOT operating costs. Estimated change in operating costs of other agencies (e.g., State Patrol, transit agencies, local jurisdictions, etc.) Capital cost of ramp metering system.
7. Identify ramp metering impacts on local streets.	Change in traffic volumes on local streets in selected corridors. Change in the length and severity of ramp queue spillover onto adjacent intersections in selected corridors.
8. Identify ramp metering impacts on transit operations.	Change in transit travel times for selected corridors. Change in transit ridership levels for selected corridors. Estimated change in operating costs for transit providers.
9. Document additional ramp metering benefits/impacts observed during the study.	Documentation only.
10. Identify similarities and differences between the Twin Cities' ramp metering system and other metropolitan areas in terms of ramp meter operation strategy employed and ramp configuration strategy.	Documentation only.
11. Identify national and international trends regarding the use of ramp metering as a traffic management strategy.	Documentation only.
12. Identify benefits/impacts of ramp metering systems documented in other national and international studies.	Documentation only.

Source: Adapted from *Twin Cities Ramp Meter Evaluation, Final Report* (Cambridge Systematics,I nc., 2001)

Footnote: VMT = vehicle-miles of travel; PMT = person-miles of travel.

The performance measures are focused on the incremental change observed between the two evaluation scenarios – "with" (meters on) and "without" (meters off). By focusing on the change occurring between the two scenarios, the evaluation team was better able to isolate the particular benefit/impact. The performance measures are not mutually exclusive and in some cases the same measure was used to test several objectives. The evaluation measures are also designed to be "neutral" and not presuppose any outcome of the ramp meter test.

While the Twin Cities ramp metering study was probably more detailed and focused that would be the typical case for an agency, it does provide some useful metrics. It also shows the value of a *before and after* approach in some situations. Most congestion metrics, when done the first time, are applied to a specific situation at *a single point in time*, but after the passage of time, a *trend analysis* is possible and perhaps the more useful. Also, as demonstrated in the Twin Cities ramp metering study, it may be useful to do *comparison analysis* with peer localities.

NCHRP Report 398, Quantifying Congestion, Volume 1

NCHRP Report 398, *Quantifying Congestion, Volume 1, Final Report* (Lomax, et al., 1997), focused on methods to measure congestion on roadway systems. Its goals were to develop "methods that are both reliable and understandable; can apply to a route, subarea, corridor, or entire urban region; can relate to simple and easy-to-obtain parameters; and can be forecast." The authors based their work on a survey of state DOTs and MPOs and a comprehensive investigation of relevant literature. The over 100 references they cited in their work are not otherwise cited here. The metrics of volume and capacity, which traditionally have been used to evaluate new infrastructure, were found inadequate to address the greater set of solutions being deployed today. These solutions require measures that capture the effects of congestion mitigation actions beyond their volume and capacity impacts.

Surveys of transportation agency practices found level of service (LOS) was the measure that was actually used most frequently while delay and travel times were the most frequent measures suggested for use. Lomax, et al. affirm that traffic volume and roadway capacity-based measures work well for many purposes and will be used by many agencies for a long time. But they argue that the needs surrounding congestion and mobility are changing and multimodal analyses will play an increasing role. They point out that while the overwhelming majority of agencies surveyed incorporate the LOS concept as a measure of congestion, there is no consensus among agencies regarding the LOS range corresponding to the threshold, or beginning, of congestion. They propose a system that solves the problems of transportation professionals and others for measurement techniques while being cognizant of data collection concerns. Key to their system are measures related to travel time and speed; these serve professionals well while being readily understood by the public. These measures are appropriate for a broad range of contexts: (1) evaluating future conditions, (2) changes due to construction, operational improvements, and management alternatives, (3) policy or land use decisions, and (4) a wide range of person and freight movement analyses.

Lomax, et al. identified two definitions of congestion in their research that respond to this broad range of contexts. Both focus on the effect of congestion. The authors used these definitions to develop a program of congestion measurement techniques.

- *Congestion* is travel time or delay in excess of that normally incurred under light or free-flow travel conditions.
- *Unacceptable congestion* is travel time or delay in excess of an agreed-upon norm. The agreed-upon norm may vary by type of transportation facility, travel mode, geographic location, and time of day.

Critical to the authors' congestion measurement techniques is the concept of defining an acceptable level of congestion. An acceptable travel speed or travel time will be different in urban and rural settings, and within each of these settings, will be different on freeways/arterials and lower-class streets. To complement their definitions of congestion, Lomax, et al. also defined *mobility* and *accessibility* somewhat differently than they have traditionally been defined.

- *Mobility* is the ability of people and goods to move quickly, easily, and cheaply to where they are destined at a speed that represents free-flow or comparably high-quality conditions.
- *Accessibility* is the achievement of travel objectives within time limits regarded as acceptable.

While these definitions are simple they are also sophisticated. They accommodate multimodal trips as well as single-mode trips. For example, as defined, an "unsatisfactory" accessibility can be "satisfied" equally by either a reduction in congestion, a switch in modes, or a change in land use patterns that reduces the need for long-distance trips altogether.

While Lomax, et al. suggest there is probably no single value that will satisfactorily capture travelers' concerns about congestion, they propose that four components can interactively do so. The authors define these four components, *duration, extent, intensity,* and *reliability*, relative to the type of system being examined in a useful matrix, which is reproduced here in Table 2.

Table 2 Overview of Methods to Measure Congestion Components

Congestion Aspect	System Type		
	Single Roadway	Corridor	Areawide Network
Duration is the amount of time congestion affects the travel system.	Hours facility operates below acceptable speed.	Hours facility operates below acceptable speed.	Set of travel time contour maps; "bandwidth" maps showing amount of congested time for system sections.
Extent is described by estimating the number of people or vehicles affected by congestion and by its geographical distribution.	Percent or amount of congested VMT or PMS; Percent or lane-miles of congested road.	Percent of VMT or PMT in congestion; Percent or miles of congested road.	Percent of trips in congestion; Person-miles or person-hours of congestion; Percent or lane-miles of congested road.
Intensity is the severity of the congestion that affects travel.	Travel rate; delay rate; relative delay rate; minute-miles; lane-mile hours.	Average speed or travel rate; delay per PMT; delay ratio.	Accessibility; Total delay in person-hours; Delay per person; Delay per PMT.
Reliability is the variation in the other three components.	Average travel rate or speed +/- standard deviation.	Average travel rate or speed +/- standard deviation; delay +/- standard deviation.	Travel time contour maps with variation lines; Average travel time +/- standard deviation; Delay +/- standard deviation.

Source: Adapted from *NCHRP Report 398*; *Quantifying Congestion* (Lomax, et al., 1997)

Footnote: VMT = vehicle-miles of travel; PMT = person-miles of travel.

These authors summarize in tables their proposed measures of congestion (Table 3) and recommend how to apply them at various scales (Table 4) and for various types of analyses (Table 5). Their report details the application of these measures to several typical analyses using examples.

Table 3 Measures of Congestion

Measure of Congestion	Method of Calculation
Travel Rate **(minutes per mile)**	$\text{Travel Rate} = \frac{\text{Travel Time (minutes)}}{\text{Segment Length (miles)}} = \frac{60}{\text{Average Speed (mph)}}$
Delay Rate **(minutes per mile)**	$\text{Delay Rate} = \text{Actual Travel Rate} - \text{Acceptable Travel Rate}$
Total Delay **(vehicle-minutes)**	$\text{Total Segment Delay} = [\text{Actual Travel Time} - \text{Acceptable Travel Time}] \text{ x Vehicle Volume}$
Corridor Mobility Index **(dimensionless)**	$\text{Corridor Mobility Index} = \frac{\text{Passenger Volume (persons) x Average Travel Speed (mph)}}{\text{Normalizing Value (e.g., 25,000 for streets, 125,000 for freeways)}}$
Relative Delay Rate **(dimensionless)**	$\text{Relative Delay Rate} = \frac{\text{Delay Rate}}{\text{Acceptable Travel Rate}}$
Delay Ratio **(dimensionless)**	$\text{Delay Ratio} = \frac{\text{Delay Rate}}{\text{Actual Travel Rate}}$
Congested Travel **(vehicle-miles)**	$\text{Congested Travel} = \text{Sum of all } [\text{Congested Segment Length (miles) x Traffic Volume (vehicles)}]$
Congested Roadway **(miles)**	$\text{Congested Roadway} = \text{Sum of all Congested Segment Lengths (miles)}$
Accessibility **(count/extent of opportunities)**	$\text{Accessibility (opportunities)} = \text{Sum of all} \begin{bmatrix} \text{Objective fulfillment opportunities (e.g., jobs)} \\ \text{where Travel Time} \leq \text{Acceptable Travel Time} \end{bmatrix}$

Source: Adapted from NCHRP Report 398; Quantifying Congestion (Lomax, et al., 1997)

Table 4: Congestion Measures for Various Levels of Analysis

Level or Scale of Analysis	Measures of Congestion										
	Travel Time	**Travel Time Difference**	**Travel Rate**	**Delay Rate**	**Total Delay**	**Relative Delay Rate**	**Delay Ratio**	**Corridor Mobility Index**	**Congested VMT/PMT**	**Congested Roadway**	**Accessibility**
Individual Roadway Locations	S	S			P						
Short Roadway Sections	P		P	P	S	S					
Long Roadway Sections or Routes		S	P	P	P	S	S				
Corridors			S	S	P	P	P	S			S
Sub-Areas					P			S	P	P	P
Regional Networks					P			S	P	P	P
Modal Analyses		P	S	S	P	P	P	P			P

Footnotes: **P** = Primary measure of congestion; **S** = Secondary measure of congestion;
VMT = Vehicle-miles of travel; PMT = Person-miles of Travel.

Table 5: Congestion Measures for Various Types of Analyses

Uses of Congestion Measures	Measures of Congestion										
	Travel Time	Travel Time Difference	Travel Rate	Delay Rate	Total Delay	Relative Delay Rate	Delay Ratio	Corridor Mobility Index	Congested VMT/PMT	Congested Roadway	Accessibility
Identification of problems	P	P	P	P	S						
Basis for government investment or policies					P			S	P	P	P
Prioritization of improvements				P	P	P	P		S	S	S
Information for private sector decisions	P		P	P	S						
Basis for national, state, regional policies and programs					P				P	P	P
Assessment of traffic controls, geometrics, regulations	P		P	P		S	S				
Assessment of transit routing, scheduling, stop placement	P	P	P	P	S						
Base case (for comparison with improvement alternatives)		P		S	P			P			P
Inputs for transportation models and air quality and energy models	P		P	P							
Measures of effectiveness for alternatives evaluation			P	P	P			P			P
Measures of land development impact	P	S	P	P	P						P
Input to zoning decisions	P	P	P								P
Basis for real-time route choice decisions	P	S	P	P							

Footnotes: **P** = Primary measure of congestion; **S** = Secondary measure of congestion;

VMT = Vehicle-miles of travel; PMT = Person-miles of Travel.

***TECHNOLOGIES**: How Do We Collect Congestion Data or Estimate It?*

Intelligent Transportation Systems (ITS) hold the promise of reducing recurring congestion (due to capacity shortfall) and nonrecurring congestion (due to incidents). These systems are evolving and depend on constantly improving technology, if the promise is to be realized. Other strategies, for example, telecommuting, also depend on harnessing new technologies or adapting them to transportation purposes from other fields. This section references some of these technologies, but by no means all. The focus here is on referencing literature that discusses technologies that are currently being used to manage congestion and to give a small sampling of recent research that shows promise.

Sensor Technologies and Data Requirements for ITS

The Federal Highway Administration sponsored a program in the early 1990s to address the emerging needs for accurate and more frequent temporal and spatial traffic flow sampling as well as to expand the types of traffic flow descriptors (Klein, et al., 1992-1995). The motivation was the data needs of the growing number of Intelligent Transportation System (ITS) applications being developed and deployed. L. A. Klein was the primary researcher and author for that effort and has expanded and updated his findings in a recent book, *Sensor Technologies and Data Requirements for ITS* (Klein, 2001). This reference provides current information on the theory and specification of non-intrusive sensors; recent findings on traffic management tactics, algorithm descriptions and performance; and data requirements in support of incident detection, ramp metering, traffic signal control, traveler information services, electronic toll collection, commercial vehicle electronic clearance, hazard warning, data reporting, and archival needs. In addition to the 550 pages in the book, an included CD-ROM provides extensive appendices that are useful for understanding current technologies and specifying them.

While the details contained in Klein's book are valuable resources for Arizona transportation professionals, the enumeration of them here is beyond the scope of this literature search. It is useful here, however, to give a brief overview of what the most relevant chapters contain.

Chapter three details the current applications of sensor data for use in traffic management strategies. Strategies from the local isolated intersection signal control to real-time adaptive signal control systems are discussed. Freeway incident detection, ramp metering, priority for emergency vehicles, and enhanced information dissemination to travelers are a few of the topics discussed. *Incident detection* algorithms, including the *California algorithms,* the *McMaster Algorithms,* and *Wireless Telephone Algorithms* are discussed. Over one hundred and thirty references are provided for those seeking more information.

To aid the traffic engineer in selecting a sensor and technology, the underlying qualities of the data needed are discussed in chapter four. Once sensors are purchased and deployed, they may remain for several years. The author discusses his perspective of future data needs and the potential of existing technologies to meet them.

Chapter five examines in detail *six sensor technologies--video, microwave radar, passive infrared, ultrasonic, passive acoustic array, and magnetic*--as well as the traditional *inductive loop*. Where variations within a technology exist, they are detailed. The theory supporting each is documented and explained with figures. Sensor combinations and relative costs are presented. Two appendices contain a sample of sensor specification summaries and a listing of sensor manufacturers and vendors. Sensor performance is linked with their proper installation in Chapter six. This chapter describes representative specifications and features of the five overhead sensor technologies, which serve to illustrate how these affect their installation calibration, and data extraction. Detailed figures and photographs of actual field installations accompany each installation discussion.

Chapter seven introduces the *transponder technology* that is rapidly growing in deployment. Transponders communicate data between vehicles and the roadside and are used widely in *electronic toll collection* and *electronic commercial vehicle credentials*. Unfortunately the standards for these operations have differed over the last decade and are still evolving. The author documents and explains these standards delving into the technical details of communication protocols. The liberal use of tables to compare and contrast information aids in understanding, especially for the non-electrical engineer.

Traffic management centers (TMCs) have a mission to deal with traffic in "real time", which is the primary reason for collecting ITS data. These centers use sensor and "data fusion" to detect, classify, identify, and track objects. *Data fusion* is the process of combining spatial and temporal data from many sensors and sources to improve the processing and interpretation of these data. The architectures and algorithms to accomplish these were originally developed in the defense communities. Chapter eight details the *sensor and data fusion algorithms* currently in use in TMCs and field locations including *pattern recognition, artificial neural networks, fuzzy logic,* and *expert systems.* Klein also discusses additional algorithms that he believes have potential for future incident detection applications including *Bayesian inference*, *Dempster-Shafer inference*, and *voting logic*. The theory, assumptions, and conditions of each algorithm are detailed and several are compared with guidelines for selection presented.

Real-Time Detection of Traffic Congestion Research

One technology that is being pursued by several researchers is the *real-time detection of traffic congestion*. What would be ideal is a "totally automated" detection technology. While such a level of automation is not currently available, several technologies show promise. In addition to the algorithms discussed by Klein (Klein, 2001) several researchers are pursuing improvements using different approaches for <u>freeway incident detection</u>. Cheu and Ritchie (Cheu and Ritchie, 1995) point out that freeway incidents are non-recurrent events that have been estimated to cause approximately 60% of the urban freeway delay in the U.S. Modeling such behavior is difficult so these researchers propose using artificial neural networks (ANNs), which do not require the specification of a model form. They report high potential for a multi-layer feedforward ANN, which they tested using simulated data and limited field-testing. Sheu, et al. (Sheu, et al., 2001) report progress in using a stochastic estimation approach to real-time estimation of delays and queue lengths for incident congestion prediction on freeways. Srinivasan, et al.

(Srinivasan, et al., 2001) report promising results after testing an algorithm using a hybrid fuzzy logic--genetic algorithm, which gives a high detection rate and low alarm rate for expressway incident detection.

Ritchie examines a different approach in collaboration with Sheu (Sheu and Ritchie, 1998 and 2001) for surface street incident detection. This approach uses stochastic system modeling to predict real-time lane traffic characteristics during incidents on surface streets. The results suggest that patterns of lane-changing fractions during incidents are significantly different from the patterns of lane-changing fractions in incident-free cases. The approach was tested on simulated data and limited real data. The work continues, with additional testing using more simulated and real incident data and the expansion of the method to more complicated cases (Sheu, Chou, and Chen, 2001).

Ritchie examines yet another approach with Logi (Logi and Ritchie, 2001) to address a combined freeway and arterial network. This approach uses a real-time *knowledge-based system* for decision support to Traffic Management Center personnel in the selection of integrated traffic control plans after the occurrence of non-recurring congestion on the network. The uniqueness of this system lies in its ability to cooperate with the operator and provide an explanation of its reasoning process. The explanation gives the reasoning that led to the selection of the control plans and an estimation of their expected effect on traffic. The researchers point out that such an explanation is very valuable to a human operator, allowing her or him to quickly assess the validity of the process and to estimate the benefits and the risks of implementing such a solution. Control is achieved through the implementation of integrated plans for traffic diversion and signal control at urban intersections and metered freeway ramps. The assessment of the approach was done through simulation-based validation and indicates improvement to the network performance, under congested conditions. The assessment also indicated some weaknesses, i.e., static assignment versus dynamic assignment and scalability, which are currently being addressed.

Adaptive Traffic Control Systems

Adaptive traffic control systems offer the promise of responding to recurrent congestion within the framework of their basic functioning. The underlying premise of these systems is that they continuously measure traffic demand in the network and optimize the signal timings at intersections (and other control points) to minimize some performance measure, e.g., delay and stops. All of this is done dynamically in real-time. These systems differ in their origins and implementations and come with an attendant host of hardware and software issues peculiar to each system. The TRB Traffic Signal Systems Committee sponsors workshops to improve the understanding of how adaptive traffic signal control systems function. A recent workshop (TRB A3A18 Committee, 2000) showcased the major systems that have an installed base in the United States: SCOOT, SCATS, OPAC, RHOADES, and LADOT's ATCS.

While the installed base of adaptive traffic control systems in the U.S. is small, about 20, worldwide well over 100 systems are currently functioning. These systems are marketed as proprietary systems and the details of the internal algorithms are typically closed to researchers. Applied research is conducted on comparison studies, either between systems or between versions of the same system. An interesting exception is work done by Bretherton, et al., at the Transport Research Laboratory (TRL), a research and consulting company based in the U.K. These researchers developed new algorithms and methods intended to minimize delays as networks become congested and licensed these to Siemens Traffic Controls, the owner of SCOOT. Based on simulation and a field trial in Kingston, London, using SCOOT and these new algorithms, they report (Bretherton, et al., 2000) significant reduction in delay. This serves as an example of the work adaptive traffic control system companies are doing to constantly incorporate new technology into their systems in order to improve their performance in managing congestion.

Field Measurement and Estimation of Congestion

NCHRP Report 398, *Quantifying Congestion, Volume 2, User's Guide* (Lomax, et al., 1997), describes how to measure congestion in the field and how to estimate congestion when field data is not present in part or whole. The measures of congestion discussed in Volume 1 of this report, and presented here previously in Table 3, rely heavily on the analysis of travel time and vehicle occupancy data. Travel time data can be collected on the entire roadway network if sufficient resources are available. Otherwise, data can be collected in an organized sampling plan, for example, on a continuous basis with a three-year cycle. Statistical analysis can be used to determine the size of the sample that represents the best compromise between resources available and sampling error. While direct measurement of travel times (and speeds) is obviously more accurate, this is not always practical. In these circumstances, surrogate techniques can be used. These techniques include using various empirical estimation models, many of which are provided in the Highway Capacity Manual (TRB, 2000). Chapter 7 of the *User's Guide* (Lomax, et. al., 1997) provides technical guidelines for measuring and estimating travel times using empirical estimation models. Another modeling approach that can provide travel time and speed estimates are microsimulation models, e.g., the Federal Highway Administration's *Traffic Software Integrated System (TSIS)* (ITT, 1999).

***STRATEGIES**: How Do We Mitigate and/or Manage Congestion?*

A great amount of information about congestion mitigation strategies exists in countless resources, which can cause a potential overload when gathering such material (Crawford, et al., 1998). Most recent sources list approximately the same strategies. These include Roper (1990), Orski (1990), Davies, et al. (1991), Henk, et al. (1991); Wesley (1992), Ouimet, et al. (1993), Sheldon, et al. (1995), Smith, et al. (1995), Elsom (1997), Meyer (1997), Turner, et al. (1998), Pal et al. (1998), and Litman (2001).

What is presented here is a representative sampling of strategies that cover the primary strategies found in the literature accessed by this technical literature search. Four sources were selected that, when taken as a whole, provide reasonably current and comprehensive coverage of the congestion mitigation strategies covered in most of the literature. These four sources are:

- Houston's 2000 Travel Rate Improvement Program (Greater Houston Partnership, circa 2001).
- A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility (Meyer, 1997)

- Mid-America Regional Council (MARC) Enhanced Congestion Management System (Cambridge Systematics, Inc., Dec. 2001, March 2001, Nov. 2000, and Jan. 2000).
- Handbook of Selected Congestion Mitigation Techniques in the United States (Crawford, et al., 1998)

Detailed information is available from diverse sources regarding the specific transportation programs of most metropolitan areas. This information is usually in the form of numerous consulting studies, annual reports, and improvement programs from a wide variety of agencies and organizations at the local, state, and federal levels. In many cases, such information has no unifying agency to bring it together and relate one document to another. Acquiring, digesting, and summarizing such information about metropolitan areas is beyond the manpower and scope of this literature review. However, these are important sources of information regarding congestion mitigation strategies. Therefore two that did have a unifying agent were selected for inclusion in this literature review: Houston and MARC (Kansas City).

The information regarding Houston is an overview of Houston's top down program strategy, which is an example of a metro area's congestion mitigation strategies that was developed by a coalition of stakeholders. The metro referenced herein, the Mid-America Regional Council (MARC), developed a Congestion Management System (CMS) to meet the unique needs of the Kansas City metropolitan area and adopted it as policy on Dec. 18, 2001. This program is comprehensive and was developed primarily by a consultant to MARC, Cambridge Systematics, Inc. An interesting note is that MARC's CMS is designed to satisfy working within the federal guidelines for a non-attainment Transportation Management Area for ozone.

A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility (Meyer, 1997) is a frequently cited reference whenever specific metropolitan congestion management strategies are developed. This work was developed for the Institute of Transportation Engineers and is arguably the most comprehensive reference work defining congestion mitigation strategies in the United States. The last reference included, *Handbook of Selected Congestion Mitigation Techniques in the United States* (Crawford, et al., 1998), has attempted to collect information from a number of large and small cities regarding their congestion management strategies and to summarize it. In contrast to the Houston and MARC sources, which provide depth about their individual programs, this reference provides a broad review of several cities programs, but only provides summary information regarding each.

Houston's 2000 Travel Rate Improvement Program (TRIP 2000)

Between the 1990 and the 2000 censuses, the population of the Houston CMSA grew 25.2 percent, according to the Census Bureau. The nation's population only increased 13.2 percent over the same period. The Houston-Galveston-Brazoria Consolidated Metropolitan Statistical Area (Houston CMSA) consists of eight counties. The metro area's population of 4.7 million is the 10th largest among U.S. metropolitan statistical areas and covers 8,778 square miles, an area slightly smaller than Massachusetts but larger than New Jersey.

A brief overview of Houston's top down program strategy is presented here as an example of a metro area's congestion mitigation strategies developed by a coalition of stakeholders (Greater Houston Partnership, circa 2001). The Greater Houston Partnership (GHP) served as an umbrella organization in developing Houston's "*2000 Travel Rate Improvement Program (TRIP 2000)*." GHP's mission is to be the primary advocate of Houston's business community and is dedicated to building economic prosperity in the region.

Houston's *Regional Mobility Plan (RMP)*, announced in 1982, coordinated the efforts of several state and local agencies in defining Houston's transportation needs and then outlined the improvements and funds required to meet those needs. Since the RMP's inception, more than $15 billion has been spent to build new tollways, arterial streets, high-occupancy vehicle lanes, and to rebuild and widen every major freeway in Houston.

The *2000 Travel Rate Improvement Plan (TRIP 2000),* brought together the same state and local agencies and the business communities, and attempts to take the next step in improving Houston's mobility. The Houston-Galveston Area Council's VISION 2022 Metropolitan Transportation Plan contains a range of strategies to improve mobility. *TRIP 2000* adds other options to the set of choices, systems and programs, but the goals are the same—decrease the time to make a trip and improve predictability of travel. No single answer was proposed in *TRIP 2000*, but great progress was called for in four major categories:

1. Expanding all elements of the transportation system ("Build More Capacity"—see Table 6).
2. Changing the way travelers use the transportation system ("Manage Demand"—(see Table 7).
3. Increasing the utilization of our existing capacity ("Increase System Efficiency"—see Table 8).
4. Providing a broad range of "urban scheme" options—the way that jobs, shops, and homes are arranged ("Change the Urban Scheme"—see Table 9).

The *TRIP 2000* acknowledged that multiple actions must be taken and certainly no single "solution" taken alone would have a significant impact. These multiple actions provide incremental solutions. Taken together, they were predicted to have a significant impact on improving mobility in Houston for years to come. The message of *TRIP 2000* is "The solution is no longer a function of simply *more*. The solution must also be *better* and *smarter*." The estimated transportation cost for needed programs between 2000 and 2022 was estimated to be $43 billion, with the breakdown being 25% for new capacity, 35% for rehabilitation, and 40% for operations and maintenance.

TRIP 2000 promotes a cost-effective, integrated network that uses the four major categories listed above to define types of improvements needed. For maximum effectiveness, the improvements in the plan form a unified, integrated, and coordinated transportation system for Houston. Additionally, all of the current systems must be expanded to accommodate growth; but, other creative ways must also be found to make the system meet Houston's needs.

The applicability of various improvements to Houston's near-term and long-term future is characterized in Table 6,

Table 7, Table 8, and Table 9. *TRIP 2000* provides guidance on the target market for each of the four major categories. It does not prescribe solutions for individual areas or corridors. It is believed that specific implementation decisions should be governed by factors such as community goals, cost effectiveness, environmental impact, social concerns, and public support.

Table 6 Houston Congestion Mitigation Strategies: "Build More Capacity"

Congestion Mitigation Strategy	Short-Term Applicability	Long-Term Applicability
1. New lanes	1S-T. Where applicable	1L-T. Where applicable
2. New streets or highways	2S-T. Where applicable	2L-T. Where applicable
3. Expanded bus service	3S-T. Where applicable	3L-T. Where applicable
4. Improve street continuity	4S-T. Where possible	4L-T. Where possible
5. New toll roads	5S-T. Self-sufficient	5L-T. Limited locations
6. Grade separation	6S-T. Where possible	6L-T. Where possible
7. Geometric design	7S-T. Retrofit	7L-T. Standard Element
8. HOV lanes	8S-T. Where possible	8L-T. Limited locations
9. Additional rail transit	9S-T. Not currently funded	9L-T. Requires financing and voter approval
10. Managed lanes	10S-T. Where possible	10L-T. Limited locations
11. Truck lanes	11S-T. Limited locations	11L-T. Limited locations
12. Freight rail improvements	12S-T. Financial feasibility unknown	12L-T. Absolutely necessary

Source: Adapted from Houston's *2000 Travel Rate Improvement Program* (GHP, circa 2001)

Table 7 Houston Congestion Mitigation Strategies: "Manage Demand"

Congestion Mitigation Strategy	Short-Term Applicability	Long-Term Applicability
1. Variable pricing	1S-T. Limited applicability	1L-T. To be determined
2. Alternative work hours	2S-T. Needs to be promoted	2L-T. Standard element
3. Telecommuting	3S-T. Needs to be promoted	3L-T. Standard element
4. Ridesharing	4S-T. Needs to be promoted	4L-T. Standard element
5. Vanpools	5S-T. Needs to be promoted	5L-T. Standard element
6. Local Bus Service	6S-T. Where applicable	6L-T. Standard element
7. Express and Park-and-Ride bus service	7S-T. High-demand corridors	7L-T. Where applicable
8. Activity center circulator buses	8S-T. Where applicable	8L-T. Where applicable
9. Neighborhood circulator buses	9S-T. Where applicable	9L-T. Where applicable
10. Demand-response and Hybrid bus service	10S-T. As needed	10L-T. As needed
11. Fare strategies	11S-T. Where appropriate	11L-T. Where appropriate

Source: Adapted from Houston's *2000 Travel Rate Improvement Program* (GHP, circa 2001)

Table 8 Houston Congestion Mitigation Strategies regarding "Increase System Efficiency"

Congestion Mitigation Strategy	Short-Term Applicability	Long-Term Applicability
1. Electronic toll collection systems	1S-T. Where possible	1L-T. Standard element
2. Intersection improvements	2S-T. Where possible	2L-T. Standard element
3. One-way streets	3S-T. Where possible	3L-T. Standard element
TranStar **Elements (the Region's Transportation Management Center)**		
4. Flow signals	4S-T. Ongoing	4L-T. Standard element
5. Traffic signal improvements	5S-T. Ongoing	5L-T. Standard element
6. Incident management	6S-T. Ongoing	6L-T. Standard element
7. Event management	7S-T. Ongoing	7L-T. Standard element
8. Changeable lane assignments	8S-T. Ongoing	8L-T. Standard element
9. Technology-based transit improvements	9S-T. Ongoing	9L-T. Standard element

Source: Adapted from Houston's *2000 Travel Rate Improvement Program* (GHP, circa 2001)

Table 9 Houston Congestion Mitigation Strategies regarding "Change the Urban Scheme"

Congestion Mitigation Strategy	Short-Term Applicability	Long-Term Applicability
1. Assessing the Transportation Impacts	1S-T. Needs to be promoted	1L-T. Standard element
2. Light rail	2S-T. Under development	2L-T. Expandable with voter approval
3. Arterial street access management	3S-T. Needs to be promoted	3L-T. Standard element
4. Parking strategies	4S-T. Needs to be promoted	4L-T. Standard element
5. "Mobility First" mentality	5S-T. Needs to be promoted	5L-T. Standard element
Home/Work Patterns		
6. Neighborhoods to "Standard"	6S-T. Ongoing	6L-T. Standard element
7. Schools to "Standard"	7S-T. Ongoing	7L-T. Standard element
8. Parks to "Standard"	8S-T. Ongoing	8L-T. Standard element
9. Bicycle and Pedestrian designs	9S-T. Ongoing	9L-T. Standard element

Note: "Standard" refers to design strategies that reduce negative impacts and encourage efficient use of the transportation system.

Source: Adapted from Houston's *2000 Travel Rate Improvement Program* (GHP, circa 2001)

The strategies detailed in the preceding tables provide a multifaceted approach to improving mobility in the Houston area. Some of these require significant capital spending. Others require policy changes or long lead times to implement. *TRIP 2000* makes eight recommendations ranging from increasing funding to improving communication among the public, planners, developers and elected officials to further improve the flow of traffic in the region. The first three recommendations focus on long-term funding:

- *Recommendation 1*: Houston must receive its fair share of funding from the Texas Department of Transportation.
- *Recommendation 2*: Houston must receive a reasonable level of federal funding.
- *Recommendation 3*: The cities and counties in the Houston area must continue to fund transportation programs.

The last five recommendations can be done in the short term as well as the long term. These are categorized as being able to be deployed with relatively little cost or policy change. They are good practices that take advantage of the system and practices Houston already have in place. These steps are deemed necessary to make progress on mobility issues in the next two decades.

- *Recommendation 4*: Raise funding levels—"Do More"
- *Recommendation 5*: Incident Management—"Do It Better"
- *Recommendation 6*: Create a Fully-Functional *TransStar*—"Be Smarter"
- *Recommendation 7*: Adopt a "Mobility-First" Mentality (essentially gets agencies and individuals to factor the impact on congestion when taking actions)
- *Recommendation 8*: Strengthen Regional Mobility Partnerships and Leadership

Trip 2000 concludes by cautioning that success depends on implementing these strategies, not just studying the issues. It states that the recommended changes impact transportation planning and operations, funding levels, the commitment of local officials and the public to the proposed policies and initiatives, and changes in development designs and patterns. It believes that in order to make a measurable, quantifiable and substantial difference in the quality of life of Houston residents, the stakeholders must stay focused on issues that effect mobility. It concludes by stating that success requires an integrated set of solutions that are comprehensive in nature. Addressing just one or two of the recommendations will not produce an acceptable solution.

A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility

The purpose of *A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility* (Meyer, 1997) is to provide multimodal strategies that can be used to provide improved mobility and accessibility. The author, Professor Michael Meyer, Georgia Institute of Technology, observes that in many communities, both "rural" and "urban", increasing levels of traffic congesting have turned once easy trips into nightmares. The lack of accurate and timely public transportation information and services has discouraged drivers from considering options other than driving alone. People are turning to community and state officials for solutions. And there are ways of dealing with traffic congestion problems.

- Some actions can be used individually, while others require mutually supportive actions implemented cooperatively by several public and private sector groups.
- Some actions focus exclusively on changes to the transportation system, while others deal with changes to land development procedures.
- Some actions provide added capacity to highway and transit systems so that passenger demand can be accommodated, while others attempt to change the characteristics of demand itself, e.g., by encouraging ridesharing.

However, no matter what type of action is considered, those who are dealing with transportation problems need to have information on different strategies that can be used to deal with congestion.

Meyer points out that to some parties congestion is not a problem. It is considered to be one straightforward result of economic prosperity. Proponents of this viewpoint argue that we will just have to live with congestion and therefore change our expectations about what is "convenient" travel. Many do not hold this viewpoint and argue instead that congestion breeds community problems that must be addressed, such as:

- Congested traffic on arterials overflows into neighborhoods causing neighborhood complaints.
- Economic growth is directly tied to a "good" transportation system, both for the actual movement of goods and services as well as for attracting/expanding community business and development.
- Good access within a community and to other parts of a metropolitan area is an important community issue not only for residents finding places to live and work but also for public safety (fire, police, medical emergency) issues.
- Quality-of-life is tied directly to the mobility and access: congestion is regarded as a symptom of its deterioration.
- Safety is perceived to be reduced when traffic is stop-and-go, often causing collisions.
- Environmental quality often degrades as congestion increases, especially air quality.

Perhaps the overarching concern among those decision-makers responsible for transportation issues is that addressing congestion effectively has often become a litmus test for effective leadership. Solutions, however, are typically difficult because they require changes in individual travel behavior, persuasive use of land use management techniques, changes in institutional structure, garnering of political will, and/or increased funding. This is especially true when dealing with long-term strategies to improve mobility and accessibility. Meyer lists eight broad concepts that should be recognized in developing congestion mitigation strategies.

1. The institutional and land use dimensions of traffic congestion make it complex; congestion is simply a symptom of much larges issues associated with community mobility and accessibility.
2. A fundamental and direct relationship exists between land use and traffic patterns; approving land developments without providing adequate transportation options will result in congested, unsafe, and environmentally damaging conditions.
3. Transportation improvements can occur in any one of three dimensions, or a combination of them: (a) enhancing services (supply), (b) changing users (demand), and (b) shifting location (land use).
4. The interrelationships of individual actions are critical in developing a strategic program; these actions must relate to regional and community objectives.
5. Be realistic in the assessment of what is likely to be accomplished; implement actions that sound engineering and planning analysis show to improve congestion problems in a cost effective, multimodal manner.
6. When implementations of actions are likely to be controversial, early and strong commitments/efforts are necessary to develop a constituency for action from interested organizations that have not traditionally been a part of the transportation planning process.
7. Private sector interests (developers, employers, business associations, etc.) must be incorporated into the planning and decision-making process; it is often in their best interest to participate and they can provide support for program adoptions.
8. Rarely is a transportation problem so localized that its mitigation doesn't affect others; cooperate with neighboring governmental jurisdictions and regional transportation agencies to find multi-jurisdictional approaches.

Meyer divides congestion mitigation strategies into two large groups, those effecting supply and those effecting demand.

Supply Oriented Congestion Mitigation Strategies

Managing the transportation system by adding new facilities or by making operational changes to improve system performance has been the most common response to transportation problems for many years. However, advancement in technologies and the use of performance measures have greatly expanded the tools available during the last two decades. The congestion mitigation strategies affecting supply can be organized in many ways. Table 10 presents the scheme that Meyer uses. For more detail regarding each strategy, including examples and their benefits/costs, see (Meyer, 1997).

Table 10 Supply Oriented Congestion Mitigation Strategies

Transportation System Category	Congestion Mitigation Strategy Affecting Supply
Urban Freeways **(Existing Systems)**	1. Freeway Incident Detection and Management System: 2. Ramp Metering: 3. Highway Information Systems: 4. Freeway Corridor Traffic Management (Including Arterial Surveillance and Control): 5. Providing Additional Lanes without Widening the Freeway: 6. High Occupancy Vehicle (HOV) Facilities: 7. Park-and-Ride Facilities: 8. Highway Pricing Strategies:
Arterials And Local Streets: Design **(Existing Systems)**	1. Super Street Arterials: 2. Intersection Improvements: 3. One-Way Streets: 4. Reversible Traffic Lanes: 5. Arterial Access Management: 6. Traffic Calming and Street Space Management:
Arterials And Local Streets: Operations **(Existing Systems)**	1. Traffic Signal Improvements: 2. Computerized/Interconnected Signal Systems: 3. Arterial Surveillance and Management: 4. Turn Prohibitions: 5. Improved Traffic Control Devices:
Arterials And Local Streets: System Management **(Existing System)**	1. High Occupancy Vehicle (HOV) Facilities on Arterials: 2. Parking Management: 3. Freight Movement Management: 4. Bicycle and Pedestrian Networks:
Enforcement	1. All Supply Strategies require Enforcement:
Building New Road Capacity	1. Multimodal Transportation Corridor Investment: 2. New Highways: 3. Access Control and Management: 4. Geometric Design: 5. Reconstruction and Traffic Management: 6. Grade Separation:
Public Transportation Services	1. System/Service Expansion 1.A. Rail/Fixed Guideway Transit Facilities: heavy rail, light rail, commuter rail, automated guideway or people movers, and HOV lanes.

	2. System/Service Operational Improvements 2.A. Fixed Route and Express Bus Services (New and Operational Changes): 2.B. Paratransit Services (Including Contract and Shuttle): 3. Supporting Actions/Policies 3.A. Fare Structures: 3.B. Multimodal Access to Transit Services/Facilities: 3.C. Multimodal/Intermodal Transit Stops and Terminals: 3.D. Transit-Oriented Development/Livable Communities: 3.E. Joint Development: 3.F. Transit-Oriented Parking Policies: 3.G. Transit Technology Applications:

Source: Adapted from *A Toolbox For Alleviating Traffic Congestion And Enhancing Mobility* (Meyer, 1997)

Demand Oriented Congestion Mitigation Strategies

Simply put, transportation demand management (TDM) is any action(s) aimed at influencing people's travel behavior in such a way that congestion is reduced. Often TDM is divided into two categories:

- Strategies or actions that are implemented at specific sites, e.g., rideshare programs at an employment site.
- Strategies that are implemented at an areawide level, e.g., growth management policies for a state or community, or the implementation of an areawide traveler information system.

Many times actions in each category can be discussed in both contexts. Meyer primarily discusses site-specific TDM actions. He does point out one example, Minneapolis/St. Paul, where TDM programs have been implemented at the corridor level. From previous work (Meyer, et al, 1994), Meyer divides the application of TDM tools among markets that are defined by geographic scale (Table 11) and lists the institutional mechanisms that are typically used to deliver TDM programs (Table 12). He posits that the market-orientation of TDM implementation is a critical dimension for successfully deploying TDM tools. For more detail regarding individual strategies see (Meyer, 1997).

Table 11 Demand Oriented Congestion Mitigation Strategies as Applied to Travel Markets

Trip Purpose	Site	Subarea/Corridor	Regional
Work	1. Carpools 2. Vanpools 3. Public/private transit 4. Bicycling/Walking 5. Alternate work hours 6. Site telecommuting 7. Parking policies	1. Subarea rideshare 2. Corridor HOV 3. Parking policies 4. Transit subsidies 5. Subarea telecommute	1. Areawide rideshare 2. Transit services 3. HOV lanes 4. Areawide pricing 5. Areawide telecommute 6. Trip reduction ordinances 7. Areawide traveler information system
Shop	1. Shuttles 2. Transit subsidies 3. Pedestrian access 4. Bicycle access 5. Urban design 6. Teleshopping	1. Shuttles 2. Park-and-ride 3. Transit services	1. Teleshopping 2. Transit subsidies 3. Areawide transit services 4. Areawide traveler information system
Tourist	1. Shuttles Parking policies 2. Transit services	1. Park-and-ride lots 2. Parking management 3. Shuttles 4. Transit services 5. Bicycle/pedestrian amenities	1. Regional transit services 2. Marketing 3. Park-and-ride lots 4. Areawide traveler information system

Source: The State-of-the-Practice of Travel Demand Management (Meyer, et al, 1994.)

Table 12 Typical Delivery Mechanisms for TDM Programs

Site	Subarea/Corridor	Regional
1. Employer Transportation Coordinator 2. Personnel department 3. Part time transportation manager 4. Voluntary participation 5. Negotiated traffic mitigation 6. Site design	1. Transportation management associations 2. Chambers of Commerce 3. Transportation Management Districts 4. City or MPO coordinator	1. Trip reduction ordinances 2. Adequate public facilities ordinances 3. Growth management 4. State, MPO, or transit agency coordination

Source: The State-of-the-Practice of Travel Demand Management (Meyer, et al, 1994.)

Meyer (Meyer, 1997) cautions that TDM programs can be short term or long term and can be spatially localized or widespread. Short term actions may focus on mitigating existing mobility/congestion problems while a strategic approach may attempt to avoid future congestion. Spatially, TDM actions can relieve spot congestion, e.g., at entrances and exits to large employment centers, while not appreciating reducing traffic on freeways or major arterials not located near the spot congestion. In practice, Meyer states, areawide levels of traffic congestion are rarely impacted by TDM actions. One exception indicated by Meyer is the application of areawide road pricing schemes, which in travel modeling studies seem to have a significant impact on travel behavior. Therefore, one should be careful not to raise unrealistic public expectations regarding the impact of TDM actions on areawide levels of traffic congestion.

Implementation, Funding and Institutional Measures

Most congestion mitigation strategies require some funding to be implemented. Institutional relationships and structures often guide the approach that is taken to implement transportation projects. In today's world, transportation planning and investment decision-making is characterized as being customer-oriented. This means that the implementation of congestion mitigation strategies should be preceded with a careful assessment and incorporated into the planning and decision-making process of those who will benefit from implementation and those who will be impacted. Therefore, market research and public involvement become critical elements of successful implementation. Meyer regards funding as an integrated element when implementing congestion management strategies.

Table 13 presents a listing of funding mechanisms. For more detail regarding any mechanism see (Meyer, 1997).

Table 13 Congestion Mitigation Strategy Funding Sources

Funding Source Category	Congestion Mitigation Strategy Funding Sources
Traditional Funding Sources	1. Fuel Taxes 2. General Revenues 3. Bonding 4. Other Revenue Sources (Targeted Taxes and Transit Revenues)
Innovative Funding Sources	1. Vehicle Use-Based Taxes 2. Public/Private Partnerships 3. Development Fees, Exactions, and Value-Added Taxation 4. Toll Roads 5. Privatization

Source: Adapted from *A Toolbox For Alleviating Traffic Congestion And Enhancing Mobility* (Meyer, 1997)

Institutional capability is one of the key ingredients to successful implementation of congestion mitigation strategies. Meyer states that such capability can include not only appropriate organizational structures for carrying out project implementation, but also having the types of skills, analytical capabilities, and adequate process that are necessary to plan appropriately for project implementation, and to operate and maintain transportation systems once in place. Most congestion mitigation programs require the active participation of state transportation agencies, transit providers, local transportation or public works organizations, and a myriad of other organizations with responsibility in transportation sector. These are complex issues; for more detail regarding them, see (Meyer, 1997).

Mid-America Regional Council Enhanced Congestion Management System

The Mid-America Regional Council, commonly referred to as MARC, serves as the association of city and county governments and the Metropolitan Planning Organization (MPO) for the bistate Kansas City region. MARC includes portions of 8 counties and 114 cities in Kansas and Missouri. According to the Census Bureau, between the 1990 and 2000 censuses, the population of the Kansas City MSA grew 12.2%, approximately the same rate at which the nation as a whole grew during this same time period, 13.3%. The 2001 population was estimated to be approximately 1.8 million.

Federal transportation legislation requires Metropolitan Planning Organizations (CMOs) to develop and implement Congestion Management Systems (CMSs) as part of the metropolitan transportation planning process (13 CFR 500). The Mid-America Regional Council (MARC) developed a CMS to meet the unique needs of the Kansas City metropolitan area and adopted it as policy on Dec. 18, 2001. Several components of the CMS were prepared by Cambridge Systematics, a transportation consulting firm (Cambridge Systematics, Inc., Dec. 2001, March 2001, Nov. 2000, and Jan. 2000). The CMS included the following five components:

- CMS Network, i.e., the subset of the high-volume network of regional streets and highways
- Performance measures
- A program for continuous data collection and system monitoring
- Identification and evaluation, as part of the planning process, of possible congestion management strategies
- Evaluation of the effectiveness of implemented strategies

Here we concentrate only on the possible congestion management strategies, which is the focus of this section. The planning studies in total are detailed and comprehensive. If more detailed information is desired, consult the original documents. These can be found on the MARC website:

www.marc.org/transportation/congestionmanagementsystem.htm.

Only a brief summary of the proposed *CMS Toolbox* (Cambridge Systematics, Inc., Dec. 2001) is presented here; if more detailed information is desired, again consult the original document. One of the references that Cambridge Systematics, Inc., used extensively in preparing their *CMS Toolbox* was Meyer's work, *A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility* (Meyer, 1997). Meyer's work is presented in detail in the previous section of this literature review.

The MARC *CMS Toolbox* of strategies was arranged in eight categories and is summarized in Table 14. It is envisioned that when local agencies implement the Enhanced Congestion Management System, the *CMS Toolbox* will be used as the starting point when evaluating alternative solutions.

The potential congestion reduction impacts are defined by Performance Measures (Cambridge Systematics, Inc., March 2001) such as reduction of single occupant vehicles (SOVs), improved travel times, and reduced delay. Analysis methods for evaluating alternative solutions/projects include the use of several types of models, i.e., the Regional Travel Model, the Transportation Demand Evaluation Model, and the Intelligent Transportation System Deployment Analysis System.

A final note of interest regards air quality issues. In 1998, MARC learned that their regional air quality designation was likely to change to non-attainment for ozone. Therefore, with this potentially new designation and because the Kansas City region is a Transportation Management Area (TMA), MARC would need to fully develop a CMS and integrate it into the regional planning process. This is part of the motivation for MARC's current effort to develop and fully implement an Enhanced CMS (ECMS) for the Kansas City region.

The Federal Aid Policy Guide 23 CFR 500A, April 8, 1999, states in part: "In a TMA designated as non-attainment for carbon monoxide and/or ozone, the CMS shall provide an appropriate analysis of all reasonable (including multimodal) travel demand reduction and operational management strategies for the corridor in which a project that will result in a significant increase in capacity for SOVs (adding general purpose lanes to an existing highway or constructing a new highway) is proposed…If the analysis demonstrates that...additional SOV capacity is warranted, then the CMS shall identify all reasonable strategies to manage the SOV facility effectively…Other travel demand reduction and operational management strategies appropriate for the corridor, but not appropriate for incorporation into the SOV facility itself shall also be identified through the CMS."

Simply put, in TMAs that are in non-attainment of ozone or carbon monoxide standards, Federal funds may not be advanced for any new project that will significantly increase the carrying capacity for SOVs unless the project results from a CMS. For MARC, SOV projects that are part of the CMS must include operational management and/or travel demand reduction strategies to effectively manage these facilities so system performance does not worsen after the facilities are constructed.

Table 14 MARC Enhanced Congestion Management System—CMS Toolbox

Transportation System Category	Congestion Mitigation Strategies
Highway Strategies	1. Increasing number of lanes without highway widening 2. Geometric design improvements 3. HOV lanes 4. Super street arterials 5. Highway widening by adding lanes
Transit Strategies	1. Reducing transit fares 2. Increasing bus route coverage or frequencies 3. Implementing Park-and-Ride lots 4. Implementing rail transit
Bicycle and Pedestrian Strategies	1. New sidewalks and designated bicycle lanes on local streets 2. Improved bicycle facilities at transit stations and other trip destinations 3. Design guidelines for Pedestrian-Oriented development 4. Improved safety of existing bicycle and pedestrian facilities 5. Exclusive non-motorized rights-of-way
Travel Demand Management (TDM) Strategies	1. Alternative work hours 2. Telecommuting 3. Ridesharing
Intelligent Transportation System (ITS) and Transportation System Management (TSM) Strategies	1. Traffic signal coordination 2. Reversible traffic lanes 3. Freeway incident detection and management systems 4. Ramp metering 5. Highway information systems 6. Advanced traveler information systems
Access Management Strategies	1. Left turn restrictions; curb cut and driveway restrictions 2. Turn lanes and new or relocated driveways and exit ramps 3. Interchange modifications 4. Minimum intersection/interchange spacing 5. Frontage roads and Collector-Distributor roads
Land Development Strategies	1. Mixed-use development 2. Infill and densification 3. Transit-oriented development
Parking and Management Strategies	1. On-street parking and standing restrictions 2. Employer/landlord parking agreements 3. Preferential or free parking for HOVs 4. Location-specific parking ordinances

Source: Adapted from *MARC Enhanced Congestion Management System: CMS Toolbox* (Cambridge Systematics, Inc., 2001)

Handbook of Selected Congestion Mitigation Techniques in the United States

The *Handbook of Selected Congestion Mitigation Techniques in the United States* (Crawford, et al., 1998) is unique in that it collected case studies for each strategy presented. The handbook's intended audiences are practitioners and transportation agencies that need a resource to help them identify congestion mitigation techniques and their potential applications. Once a strategy is identified in the manual, the user will be able to contact the appropriate agency discussed in the case study or studies that support that strategy. The case study descriptions give basic information about the strategy's development, costs, and implementation, as well as some basic information about the metropolitan area where the strategy is being deployed.

It is important to note that the information from this source is approximately 5 years old at the time of this literature review. Also, a critical reading by the TAC supervising the project for which this literature review was conducted found some examples of data that appears to be in error or at least out of date. While this diminishes the value of the reference, it is still judged sufficiently valuable to include in this literature review. It is the only source that was found that contains case studies for numerous agencies and therefore provides a unique comparative view across agencies of diverse locals and sizes. However, the reader is cautioned that the value of this reference is probably limited to this comparative view and not to accept any specific details without first checking with the agency involved to get a current update and/or verification of the information.

The authors introduce terms that are common in congestion management. When discussing the entire system, the term used is *congestion management system* or CMS. The overarching term used for congestion mitigation strategies is *transportation control measures* or TCMs. Strategies that seek to improve traffic flow are called *transportation system management* or TSM strategies. Strategies seeking to modify travel demand and behavior are called *transportation demand management* or TDM strategies.

A broad cross section of metropolitan area populations is presented in the case studies. In addition, case studies are presented from geographically diverse areas. In some instances, such as HOV lanes, there are certain congestion mitigation strategies that are financially feasible only in areas with very large populations. Other strategies, such as traffic flow improvements, are common among all urban areas managing their traffic congestion. Larger cities are more likely to have a more developed public transit system, which takes advantage of transit centers, signal preemption, transitways, as well as supporting park-and-ride facilities and HOV lanes. Many of these components are capital-intensive and require financing through public bonds. Larger cities are also more likely to employ TDM as a tool in mitigating traffic congestion. With the presence of large employers at downtown locations or campus-style developments in the suburban areas, greater benefits of transportation demand management may occur. One adverse characteristic that large cities have on TDM is that the employment base becomes so large and diverse that it can discourage certain forms of TDM.

Smaller urban areas commonly use less expensive measures to manage traffic congestion. Signal improvements, intersection improvements, construction of additional travel lanes and the like are typically used to improve the flow of traffic. The use of lower cost strategies is driven by the competition for transportation funding and the need to mitigate congestion in larger cities. Little emphasis is placed on managing the demand on the transportation system of smaller areas. Small cities are not likely to pursue demand management projects because congestion has not reached an intolerable level, and greater benefit-cost ratios are obtained through traditional TSM projects.

The authors caution that congestion mitigation should not be approached in a piecemeal manner; rather it should be approached with a well planned array of complementary measures implemented as a coordinated program. The authors advise that a well planned program of 15 to 20 separate measures, which consist of inter-related measures, can be three to four times more effective than any of those measure individually. Such a program makes efficient use of scarce public tax dollars.

The strategies developed by Crawford, et al., are presented here using the same organization scheme as that used in the handbook. This scheme divides the strategies into six broad categories and lists the strategies or elements within each category as a subtopic. The population involved with each case study is listed; this gives an indication which strategies might be best suited to "rural" and which to "urban" applications.

A. INTELLIGENT TRANSPORTATION SYSTEMS

A.1 Freeway Service Patrol (FSP): generally consist of staffed vehicles that patrol freeways to provide assistance to stranded motorists. Sponsors and participants include state DOTs, cities, transit agencies, and private companies. Case studies show that these programs have greatly reduced peak hour congestion caused by traffic incidents.

i) *San Diego, CA*: (1990 pop – 2,498,016); Freeway Service Patrol; San Diego Association of Governments; $2.3 million cost; 212 FSP freeway miles.

ii) *Denver, CO:* (1990 pop – 1,622,980); Mile High Courtesy Patrol; Colorado DOT; $632,250 annual cost; 43 FSP freeway miles.

iii) *Minneapolis, MN:* (1990 pop – 2,538,776); Highway Helper; Minnesota DOT; $610,000 annual cost; 71 FSP freeway miles.

iv) *Charlotte/Mecklenburg, NC:* (1990 pop – 1,162,140); Motorist Assistant Program; $191,068 annual cost; 17 FSP freeway miles.

v) *Houston, TX:* (1990 pop – 3,321,926); Motorist Assistant Program; $1,500,000 annual cost; 529 FSP freeway miles.

A.2 Ramp Meters: ramp meters are a proven, cost-effective technique for improving traffic flow. Ramp metering programs have had tremendous impact on freeway congestion in cities across the country.

i) *Oakland, CA:* (1990 pop – 2,080,434); Federal, state and Santa Clara Traffic Authority; $4,900,000 cost; 18 program freeway miles.

ii) *Denver, CO:* (1990 pop – 1,622,980); State of Colorado; $40,000 per ramp meter; 249 freeway miles.

iii) *Portland, OR:* (1990 pop – 1,515,452); State of Oregon; $250,000 per ramp meter, $50,000 annual operating costs; 81 freeway miles.

iv) *Salt Lake City, UT:* (1990 pop – 1,072,227); Federal and State; $75,000 per ramp meter ($1,000,000 with geometric improvements); 70 freeway miles.

A.3 Variable Message Sign (VMS): A VMS offers the ability to effectively communicate traffic information to motorists. The information can be changed quickly to match the immediate traffic conditions. VMS can be portable or permanent.

i) *Cleveland, OH:* (1990 pop – 2,202,069); Federal and state; $34,000 per sign; one permanent and two portable signs.

ii) *Houston, TX:* (1990 pop – 3,321,926); State; $75,000 to $100,000; 75 permanent signs.

iii) *Laredo, TX:* (1990 pop – 133,239); State; $150-$200,000; 2 permanent and 2 portable flap signs.

iv) *Madison, WI:* (1990 pop – 367,085); State; $32,000; signs with 12 flap/flip disk, solid matrix LED.

v) *Cheyenne, WY:* (1990 pop – 20,008); State; $30,000 per sign; 6 permanent overhead and 1 roadside signs.

A.4 Incident Management (IM): involves the pre-planned coordination of personnel, equipment, and materials, with the goal of reducing the time it takes for an incident detection, response, and clearance. Incident management programs use various combinations of strategies and technologies in achieving the goal of clearing the roadway, including *roving service vehicles, motorist aid call boxes, dedicated cellular phone lines, incident management teams, motorist information systems, traffic diversion techniques,* and *alternate route identification*. Incident management technologies include *traffic surveillance systems,* which incorporate *mainline detectors, VMS, closed-circuit television, advanced communications systems,* and *highway advisory radios (HAR)*.

i) *Charlotte, NC:* (1990 pop – 1,162,140); Federal and state; $500,000 annually; primary services not available; 28 IM freeway miles.

ii) *Portland, OR:* (1990 pop – 1,515,452); Federal and state; $750,000 in start-up cost and $1,500,000 annually; primary services include traffic monitoring with surveillance equipment, VMS, radio, traffic signal and ramp meter changes; 81 IM freeway miles.

iii) *Seattle, WA:* (1990 pop – 2,033,128); State; $17,900,000 start-up; primary services include cable television, variable message sign, highway advisory radio, Internet; 240 IM freeway miles.

A.5 Transportation Management Centers (TMCs): these are systems developed to address growing congestion experienced on roadways. Real-time information is available within a TMC, allowing operators, planners, and engineers to interact and make immediate, informed decisions regarding transportation. Information about incidents, accidents, road and bridge closures, and emergency situations are gathered through equipment, such as loop detectors and closed circuit television, and then disseminated to the public. *Automated congestion* *detection, automated response plans, freeway ramp meters, traffic signals,* and *video cameras* can be used to support and control traffic and incidents from within the TMC. This equipment helps reduce the time required to detect and respond to congestion-causing incidents by allowing immediate identification of a problem and determining the proper response. TMC personnel, along with agencies such as state DOTs, local agencies, and emergency response teams, coordinate and develop plans to use this technology in order to quickly provide important information to motorists. *VMS* and *HAR* release incident information, alternative routes, or possible detours to aid motorists in their daily commute.

i) *Atlanta, GA:* (1990 pop – 2,959,500); Navigator; Federal, state, and Atlanta Regional Commission; $11.0 million start-up; primary services include automated incident detection, 317 fixed black/white TV units, 56 radar units, 400 video monitors, 25 VMS, highway advisory radio, 5 ramp meters, helicopter-mounted gyroscope camera; 49 TMC freeway miles.

ii) *Minneapolis, MN:* (1990 pop – 2,538,776); TMC; sponsor not available; $40.0 million (from 1970-1995); primary services include 380 ramp meters, 156 closed circuit television cameras, communication system with 135 miles of fiber optic cable, 400 field microprocessors, 54 VMS, 3,000 traffic detectors, and information via radio programming and cable TV, telephone call-in capability, and web-site; 203 freeway miles.

iii) *Providence, RI:* (1990 pop – 1,134,350); Transportation Management Center; Federal and state; $1.95 million start-up; primary services include automated incident detection, variable message signs, closed circuit TV, highway advisory radio; 52 TMC freeway miles.

iv) *San Antonio, TX:* (1990 pop – 1,324,749); Transguide; Federal and state; $32.0 million (phase I); primary services include inductive loops, 59 cameras, 359 lane control signals, 52 VMS; 109 TMC freeway miles.

v) *Milwaukee, WI:* (1990 pop – 1,432,149); Monitor; sponsor not available; $8.5 million start-up; primary services include 90 ramp meters, 14 VMS, closed circuit TV, highway radio advisories; 80 TMC freeway miles.

B. HIGH-OCCUPANCY VEHICLE SYSTEMS

B.1 <u>High Occupancy Vehicle (HOV) Lanes</u>: HOV lanes work to alleviate congestion by reducing the number of single occupant vehicles (SOVs). Requirements vary with some requiring 2 or more passengers (2+ HOV) per vehicle, others require 3+ HOV. It is common to allow one person motorcycles to drive the HOV lane. Some jurisdictions prohibit trucks over certain threshold weights from driving in HOV lanes. Benefits of using HOV lanes include travel time savings, increases in transit use, and overall increased capacity of the highway facilities for both HOV lanes and general purpose (GP) lanes. Some HOV lane person per vehicle requirements are enforced only during peak periods while others are enforced 24 hours per day.

i) *Minneapolis, MN:* (1990 pop – 2,538,776); I-394; Minnesota DOT, FHWA, Metropolitan Council, Metropolitan Transit Commission, Hennepin County, and the City of Minneapolis; $17.3 million; 11 HOV miles with 3 miles of reversible HOV lanes and 8 miles of concurrent-flow HOV lanes; 330 freeway miles.

ii) *Long Island, NY:* (1990 pop – 2,609,212); I-495; NY state DOT; $107.0 million; 12 HOV miles, painted buffer zone, concurrent; 720 freeway miles.

iii) *Dallas, TX:* (1990 pop – 2,676,248); I-30, I-35E North, and I-635; Texas DOT, Dallas Area Rapid Transit; $12.2 million (I-30), $7.0 million (I-35E), and $16.3 million (I-635); 35.4 HOV miles, barrier-separated, contraflow and buffer-separated concurrent flow; 579 freeway miles.

iv) *Seattle, WA:* (1990 pop – 2,033,128); I-5; Federal and state; $7.6 million, 7.7 miles southbound HOV, 6.2 northbound HOV miles; 240 freeway miles.

B.2 High Occupancy Toll Lanes (HOT) and Congestion Pricing (CP): the practice of tolling HOV lanes is a relatively new concept when certain HOV facilities were not being used efficiently for congestion management. In such instances, commuters may, for a fee, use HOV lanes even if their vehicle has less than the minimum number of persons that is required on the facility. *Windshield decals* and *electronic on-board vehicle transponders* have simplified the tasks of collecting tolls. Since 1995, a few states have conducted HOT lane demonstration projects including concepts such as *time of day pricing*, *private-for-profit facilities,* and the benefits of having HOT lanes require 2+ persons per vehicle versus 3+ persons per vehicle.

i) *Orange County, CA:* (1990 pop – 2,410,668); California State Route 91 Variable –Toll Express Lanes; California Private Transportation Company; $126 million; primary services include 10 miles, two toll lanes each direction, buffer with channelizers, electronic transponders, carpool usage is up 18% since its opening; 75 freeway miles

ii) *San Diego, CA:* (1990 pop – 2,498,016); Interstate 15 Congestion Pricing Project Express Pass Program; San Diego Association of Governments, California DOT, FHWA, and Federal Transit Administration; $9.95 million; primary services include 8 miles, two toll lanes (reversible), barriers, transponders; 314 freeway miles.

iii) *Lee County, FL:* (1990 pop – 335,113); Time of Day Pricing Program; DOT in Lee County (Leeway Services); cost not available; primary services include 25% of motorists indicated using the facility during non-peak hours due to reduced tolls; 34 freeway miles.

iv) *Houston, TX:* (1990 pop – 3,321,926); I-10 High Occupancy Tolls (Priority Lane Pricing); Metropolitan Transit Authority of Harris County, Texas DOT, FHWA, Federal Transit Administration; $870,000; primary services include 13.1 miles, one lane (reversible), barriers, electronic transponders; 529 freeway miles.

B.3 Rideshare: this concept means that two or more people share a daily commute to or from work or some other common destination. Local governments and private companies have been actively promoting formal and informal ridesharing programs to combat increasing traffic congestion and air quality problems. *Carpools*, *vanpools*, and *guaranteed rides home* are elements of ridesharing. The primary benefits received by employees who use ridesharing are a decrease in personal commuting expenses and possible travel time savings that are possible with the ability to use HOV lanes on freeways. Some employers also provide *preferred parking* to carpool and vanpool vehicles. Preferred parking can involve premium spaces and/or subsidized fees where there is a cost involved.

i) *Boulder, CO:* (1990 pop - 225,339); Rideshare, Guaranteed Ride Home; Boulder Community Hospital, City of Boulder, and Community Transit Agency; cost not available; participation not available, primary services include financial incentives.

ii) *Denver, CO:* (1990 pop. - 1,622,980); The Guaranteed Ride Home Program, RideArrangers/ECO Pass; Denver Regional Council of Governments and individual employers; cost not available, participation by 1,201 employers and 43,500 employees (1997); primary services include guaranteed taxi rides home and use of public transportation.

iii) *Montgomery County, MD:* (1990 pop. - 4,222,830); Government Employee Transit Incentives, (Get-In) Program; Montgomery County; $35,000 for implementation; participation by over 100 county employees; primary service include monthly subsidy for not driving alone.

iv) *Austin, TX:* (1990 pop. - 846,227); Ridefinders; Capital Metro; cost not available; participation by 33,000 (1998 average monthly ridership), 111 vans as of Aug. 1998; primary services include computerized ride matching, vanpool program, employer assistance, and guaranteed ride home.

v) *Bremerton, WA:* (1990 pop. - 189,731); Smart Commuter; Washington State; reimbursement of $16,577 to taxi companies who provided guaranteed rides home; participation by 882 guaranteed rides home since 1994; primary services include vanpools, guaranteed rides home, park-and-ride lots.

C. CONSTRUCTION

C.1 Night Construction: construction projects often cause traffic congestion. One strategy to lessen the inconvenience of construction projects on motorists is to conduct road work during nighttime hours. This lessens impacts of lane closures since there are fewer vehicles on the road during nighttime. However, nighttime construction can produce significant noise problems and is more costly than daytime construction.

i) *Los Angeles, CA:* (1990 pop – 8,863,052); public perception is that complaints re highest if work is still in progress when early morning commute hours begin.

ii) *St. Louis, MO:* (1990 pop – 2,492,348); it has been reported that the levels of frustration that motorists had regarding bumper-to-bumper traffic associated with daytime construction projects has decreased.

iii) *Columbus, OH:* (1990 pop – 1,345,450); many in the public want to know why more construction work cannot be performed at night. Public enjoys faster completion when projects done at night and also find use of tower lighting and portable lighting very helpful.

iv) *Harrisburg, PA:* (1990 pop – 587,986); public almost always prefers night construction. Pennsylvania Turnpike Commission has determined that the less inconvenience there is for motorists, the more support there is for the project. The fact that traffic is not inhibited makes construction work more tolerable in the eyes of the public.

v) *Seattle, WA:* (1990 pop – 2,033,128); a University of Washington survey reported that the public felt that night construction was a very effective and efficient way to complete roadway projects more quickly.

C.2 Construction and Public Awareness/Relations: By providing as much information as possible to the public, including alternate routes, transportation agencies can realize less public resistance to construction projects. Some agencies even make the public an active part of the process, a step that can even gain public support of the project. Public awareness of projects is done with *informal workshops* and *public hearings*. Many agencies have formed project teams with the specific duty of informing the public of upcoming projects, as well as projects scheduled to begin several years in the future. Other methods include *brochures, press releases, media kits, telephone hotlines, television (public access channels), highway advisory radio (HAR),* and the *Internet*. Construction public awareness usually requires cooperation between the FHWA, DOTs, public safety agencies, and other local agencies.

i) *Montgomery, AL:* (1990 pop –292,517); $90,000 annual cost; primary services include press releases, bulletins, Internet, and TV; staffing not available.

ii) *Detroit Lakes, MN:* (1990 pop –7,141); $45,000 annual cost; primary services include media kits, press releases, radio, Internet, and media interviews; one public relations employee (Detroit Lakes, District 4)

iii) *Raleigh, NC:* (1990 pop –858,485); cost not available; primary services include newspaper advertisements, public hearings, Internet, radio, and mailing list; five public relations employees (statewide).

iv) *Columbia, SC:* (1990 pop –453,932); cost not available; primary services include highway advisory radio, Internet, brochures, and phone line; six public relations employees (statewide).

v) *Fort Worth, TX:* (1990 pop –1,361,034); cost not available; primary services include TV, radio, brochures, bulletin, and press releases; three pubic relations employees (Fort Worth District).

C.3 Lane Closures: for a variety of reasons, lanes must be closed to increase the safety and maneuverability of constructing crews. Where possible, *alternative routes* are preferable. High capacity roadways with four or more lanes are less sensitive to lane closures. Low capacity roadways with two or three lanes can be severely affected by lane closures, which produce significant time travel delays or require roadway detours.

i) *Little Rock, AR:* (1990 pop –513,117); state DOT only allows lane closures at night between 7:00 pm and 7:00 am; elements used include barricades, lane striping, local newspaper, and local traffic reports; the policy of conducting lane closures during the evening and early morning hrs. resulted from the public outcry against their occurrence during daytime hours.

ii) *Tallahassee, FL:* (1990 pop –233,609); Florida DOT only allows lane closures during non-peak periods; elements used include signing, radio, TV, and newspaper.

iii) *Baltimore, MD:* (1990 pop –2,382,172); Maryland DOT uses nighttime lane closures, with few peak-time closures; elements included posted signs, variable message signs, public meetings, toll-free number, and radio.

iv) *Dallas, TX:* (1990 pop –2,676,248); City of Dallas and Texas DOT Dallas District allow no peak hour lane closures; requiring that lane closures be conducted at non-peak periods actually save the taxpayers substantially more in cost due to travel time savings and inconvenience that the additional daily cost of the construction project itself.

D. ROAD IMPROVEMENTS

D.1 Traffic Calming: *traffic calming* is a strategy to mitigate traffic congestion on local streets. As traffic volumes increase on arterials causing increased delays at signalized intersections, some traffic will divert to local streets. Traffic using local streets as a throughway can cause congestion as well as exhibit higher speeds than the local residential traffic. As a result, neighborhoods become concerned abut the safety of children. Traffic calming devices can increase response times of emergency vehicles and technology is sought which can "calm" traffic while still keeping response times low. Devices include *speed watch programs, speed humps, traffic circles, raised crossings, raised intersections, chokers,* and *delineators.*

i) *Boulder, CO:* (1990 pop –85,127); Neighborhood Traffic Mitigation Program; $875,000 cost the first year; CO DOT, Police Department, Transportation Division, Neighborhood Liaison's Office, and the Fire Department; primary services are speed humps (24) traffic circles (8), raised crossings (2), and raised intersection (1).

ii) *Las Vegas, NV:* (1990 pop –258,204); Neighborhood Traffic Management Program; $180,000 for FY 1998; primary services include road humps, chokers, roundabouts, delineators.

iii) *Portland, OR:* (1990 pop –463,634); The Traffic Calming Program; $1,500,000 per year used mainly for capital and operating expenses; City of Portland, primary services include curb extensions, slow points, traffic circles and speed bumps.

iv) *Ft. Worth, TX:* (1990 pop –447,679); The Traffic Calming Program; $32,000 for implementation; City of Ft. Worth; primary services include 36 speed humps on five streets.

v) *Seattle, WA:* (1990 pop –516,259); Neighborhood Traffic Control Program; $350,000 dedicated the Traffic Circle Program; Seattle Transportation;

primary services include speed watch programs, traffic circles (30), chicanes (12 sets), and speed humps (30 on 6 streets).

D.2 Access Management: arterial traffic flow will decrease, causing congestion, when encountering vehicular conflicts from vehicles entering from intersections and driveways. This can be managed by reducing the number of such conflicts. Strategies include *reducing access points, separating access points,* and *removing slower traffic*. Features to accomplish this include the *spacing and design of driveways, median use* and the *number of median openings, shared access improvements, turn lanes,* and *freeway interchange spacing and design*.

i) *Irvine, CA:* (1990 pop –110,330); Alton Parkway; City of Irvine; cost not available; 8.5 mile, four-lane, raised median roadway; two-lane roadway converted to a four-lane roadway with a raised median; access management is a major component in land planning and development in this "young" community, incorporated in 1971.

ii) *Melbourne Area, FL:* (1990 pop –60,034); New Haven Ave.; Florida DOT; $4,230,000 cost; 5.1 mile four-lane divided arterial; 16 median openings were closed and 42 full openings were modified to directional median openings; traffic vols. increased dramatically and travel speeds increased.

iii) *Atlanta, GA:* (1990 pop –393,929); Memorial Drive (SR 10); $3,919,876 cost; Georgia DOT; 4.34 mi. section replaced two-way left turn lane with raised median; 7 large intersections were not provided with median openings.

iv) *Overland Park, KS:* (1990 pop –111,790); 135th Street (Kansas State Hwy 150); Cities of Overland Park, Leawood, and Olathe; cost not available; study produced concept of 9 mile multi-lane arterial with median, and limited right-turn-only access; median openings every half-mile, right-turn-only access, and reverse frontage roads (along the back sides of properties) every quarter-mile in areas of intensive development; concept applied as uniformly as possible with exceptions handled on a case-by-case basis.

v) *Plano, TX:* (1990 pop –127,885); Access Management / Custer Road; $6,326,992 cost; City of Plano; 6-lane roadway with 24-foot median; design follows Thoroughfare Standards Rules and Regulations Manual, which outlines City's policies concerning access management.

D.3 Bicycle/Pedestrian Paths: currently, only 2% of Americans commute to work by bicycle. 1990 poll reported that respondents would bicycle to work if facilities that made it fun, safe, and convenient were in place. These facilities include *bike paths, bike lanes, bike trails, bike lockers,* and *showers*. The most desired facility was a bicycle lane.

i) *Davis, CA:* (1990 pop –46,332); Bicycle Program; City of Davis, State of California, and local developers; cost not available; primary services include 45 mi. of bike lane and 48 mi. of bike path; effects of this system are quite impressive. Of all trips made in Davis, 20% to 25% of them are by bicycle.

ii) *Minneapolis, MN:* (1990 pop –368,383); The Cedar Lake Trail; $1,100,000 cost; Cedar Lake Park Association, Minneapolis Department of Public Works, Minneapolis Park and Recreation Board, and the Hennepin County

Regional Railroad Authority; primary services include The 3.5 mile Cedar Lake Bicycle Highway, 35 miles of lanes, 56 miles of paths, and parking facilities (46 bike racks and 14 bike lockers).

iii) *St. Louis, MO:* (1990 pop –396,685); Regional Bicycle and Pedestrian Advisory Committee; cost not available; primary services include advise, coordinate, promote, and implement bicycle and pedestrian service plans; Council oversees 12 counties and approves funding for bicycle and pedestrian projects submitted by cities within their region.

iv) *Austin, TX:* (1990 pop –472,020); Bicycle and Pedestrian Program; $750,000 in grants; Austin Transportation Study, Texas DOT, City of Austin Department of Public Works and Transportation; primary services are bicycle lanes, wide curb lanes, traisl, sidewalks, and crosswalks; solicits grants for specific projects and promotes guidelines and bicycle use.

v) *Madison, WI:* (1990 pop –190,766); Madison Bicycle and Pedestrian Division; cost not available; Wisconsin DOT, the Governor's Bicycle Advisory Council, and the City of Madison, Traffic Engineering Division; primary services include 13 miles of bike lanes, 20 miles of bike paths, 59 miles of mixed traffic routes, and 7 sidewalks as of 1990.

D.4 Traffic Signalization: improving traffic signalization systems can have a very large impact on traffic congestion. They can improve travel time and lower fuel consumption and vehicle emissions. These improvements include the installation, replacement, and/or upgrade of traffic signals, and/or the *coordination and synchronization of a series of traffic signals.* Technologies that are used include *airplane surveillance, loop detection systems, on-line computerized systems, automatic vehicle location systems*, and *video cameras*.

i) *San Francisco Bay Area, CA:* (1990 pop –6,249,881); Regional Traffic Signalization and Operation Program; $18.0 million cost; Metropolitan Transportation Commission; primary services included retiming or replacement of existing regional traffic signals; benefits include 15% improvement in travel times, a $1.2 million fuel cost savings, and reduced auto emissions of approximately 110 tons per year.

ii) *Montgomery County, MD:* (1990 pop –4,222,830); Transportation Management Center; $3.0 million annually; County of Montgomery, U.S. DOT, and Maryland DOT; primary services included traffic responsive signal system, inductance loops, microwave detection, machine vision, traffic video, camera system, and aerial traffic monitoring; benefits include 14$-20% increased rush hour travel speeds and 17$-37% decreases in delay.

iii) *Greater Detroit (Oakland County), MI:* (1990 pop –4,266,654); FAST-TRAC; $7.0 million for FY 1998; The County of Oakland; primary services included upgrade, maintain, coordinate, and replace traffic signal systems; benefits include reports that communities within the county have experienced positive effects (such as reduced traffic accidents) as a result of the increased signalization.

iv) *Laredo, TX:* (1990 pop –133,239); Traffic Signalization System; per year $200,000 to install 4 new signals plus $20,000 per year on upgrades and maintenance; Texas DOT; primary services include 63 traffic signals using a closed loop, on line NAZTEZ program; traffic relief benefits have caused DOT to see approval for additional upgrades.

v) *Houston, TX:* (1990 pop –3,321,926); TranStar; $13.454 million cost; City of Houston, Harris County, Metropolitan Transit Authority of Harris County, and Texas DOT; primary services included computerized traffic signals, computerized freeway management system, roadway sensors, and automatic vehicle location systems; this is one of the largest undertakings of an on-line, real-time, computerized system that manages 3,000 intersections.

D.5 Intersection Improvements: these improvements have the ability to reduce collisions and to relieve congestion. Costs to improve intersections vary considerably and include the incorporation of storage bays and channels that allow through traffic to more rapidly and safely pass vehicles that are decelerating to make left or right turning movements. Improvements include *left turn storage, right turn storage, right turn channelization, lane designation,* and *dual left turn lanes*.

i) *Albuquerque, NM:* (1990 pop – 384,915); PWD; cost not available; City of Albuquerque; primary services included left turn storage (or bays) and dual left turn lanes; when deciding if changes are to be implemented, the department takes into account available resources, traffic capacity public complaints, accidents, and side streets and intersections in the vicinity.

ii) *Amarillo, TX:* (1990 pop – 157,571); Public Works Division; cost not available; Texas DOT; primary service includes right turn channelization; no records available on effects.

iii) *Corpus Christi, TX:* (1990 pop – 257,453); Metropolitan Planning Organization; $200,000 to $250,000 annually; City of Corpus Christi; primary services include right turn channelization and left turn channelization; City reports improvements have increased traffic volumes greatly and accidents at one sampled intersection has reduced.

iv) *Vancouver, WA:* (1990 pop – 463,634); Public Works, Transportation Agency; double left turn lanes ($400,000), signal intersection improvements ($135,000-$550,000), signal modifications and provisions of dual left-turn lane ($146,000); U.S. DOT and Washington DOT; primary services for this single intersection included right turn channels (most with a raised median), left turn pockets, and islands for traffic signals; reported that traffic accidents reduced at this intersection.

D.6 Express lanes: these lanes provide dedicated capacity on freeways for vehicles that are traveling a significant distance within or through a portion of a metropolitan area. Motorists are able to bypass several interchanges and the associated congestion while driving in express lanes. Some express lanes exist for short distances (less than 2 miles) while other span several miles. Designs include *separate overhead structures* to *same-grade adjacent lanes*. Express lanes are generally very expensive and there use is somewhat limited to cities of greater size or corridors between cities.

i) *Chicago, IL:* (1990 pop – 7,410,858); Kennedy Expressway; part of a $435 million overall highway reconstruction; Illinois DOT; ten reversible express lanes totaling 7.5 miles; benefits are lowered commute times and increased safety for travelers coming to or from the Chicago area.

ii) *State of Maryland:* (1990 pop – not applicable); Interstate 270; part of a $200 million project; Maryland DOT; eight express lanes divided from four local lanes by Jersey Barriers; benefits are reduced amount of weaving and reduction in speeds that result on adjacent local lanes.

iii) *San Antonio, TX:* (1990 pop – 1,324,749); "Downtown Y" Project; $272 million; Texas DOT; 10 miles of double-decked, 8 to 10 lane, segmental winged-T bridge; benefits include 38% increase in Average Daily Traffic between 1990 and 1996 and good travel times to the CBD.

iv) *Austin, TX:* (1990 pop – 846,227); I-35 Elevated Express Lanes; $5,617,809 cost; Texas DOT; two, double lane, 1.3 mile long elevated express lanes; positive safety benefits are inferred from more frequent and more severe accidents occurring on the lower levels of I-35 (non-express lanes).

v) *Seattle, WA:* (1990 pop – 2,033,128); I-5 and I-90 Express Lanes; cost not available; Washington DOT; cost not available; HOV and SOV manually reversible lanes; benefits not definable since widening occurred simultaneously with addition of express lanes; observations indicate that traffic is not as peak-directional as engineers had predicted. Inbound traffic is nearly as heavy as outbound traffic during evening peak hours. Drive times are reportedly shorter on the express lanes but congestion is prevalent at ingress and egress points in the express lane.

D.7 <u>Border Crossings</u>: bottlenecks often occur on highways that cross international boundaries. Truck freight movement has increased since development of Free Trade Zones and NAFTA. Queues at border crossings can extend onto the traffic network of the adjacent cities, creating congestion at both the crossings and the adjacent cities.

i) *San Diego, CA:* (1990 pop – 1,110,623); San Ysidro and Otay Mesa Land-Border Ports; cost not available; U.S. Customs Department, INS, and the Department of Agriculture; Otay port opened in 1985; San Ysidro port was the largest land-border port in the world in 1996.

ii) *Detroit, MI:* (1990 pop – 1,027,974); Detroit/Windsor Tunnel and Ambassador Bridge Border Crossing; cost not available; the Ambassador Bridge is the most heavily used port for commercial traffic traveling to Canada and recently installed a commuter card and a PORTPASS system.

iii) *El Paso, TX:* (1990 pop – 515,342); Zaragoza Bridge and Bridge of the Americas; $8.0 million upgrade cost for each bridge; Texas DOT and City of El Paso; primary services included an increase in the number of structures and lanes for passenger and commercial traffic, safer pedestrian walkways, and greater number of check points.

iv) *Laredo, TX:* (1990 pop – 122,899); Laredo Northwest International Bridge; $59.3 million; U.S. DOT and Texas DOT; primary services included an 8 lane int'l. bridge, a Laredo-managed toll plaza and export lot, federal inspection offices and processing facilities, and state-managed hwy facilities.

D.8 Added Single Occupant Vehicle (SOV) Lanes: adding lanes increases the carrying capacity and traffic flow of a roadway. SOV lanes are typically added through *reconstruction* or *restriping*. Restriping can be done *by removing parking spaces* along the curb, the *conversion of shoulders* to travel lanes, or *narrowing lanes* so as to allow more space for an additional travel lane. Reconstruction increases the curb-to-curb width.

i) *Wichita, KS:* (1990 pop – 304,017); Maize Road Projects; $7.112 million; City of Wichita; widened 2-lane county highway to a 4-lane urban section; increased capacity has led to less congestion and higher levels of safety.

ii) *Amarillo, TX:* (1990 pop – 157,571); S.W. 9th Avenue, Washington Street, Coulter Street., S.W. 45th Avenue, and Eastern Street; costs respectively are $2,000, not available, $493,928, $499,851, and $1,105,621; Craig Methodist Retirement Center and City of Amarillo; increased lanes via striping and/or reconstruction; inconclusive assessment suggests that restriping has had a beneficial effect on traffic flow and decreased the number of traffic collisions.

iii) *Waco, TX:* (1990 pop – 103,590); Garden Drive Widening and Extension Project; $1.6 million; City of Waco and Texas DOT; four travel lanes and a center turn line resulted from the extension and widening of a two lane facility; no effects have been reported.

E. PUBLIC TRANSIT

E.1 Bus: Transit buses produce significantly less air pollution per person and are more efficient of roadway space and energy resources than all other highway modes of travel. Fixed route bus services operates on regularly scheduled routes, a variation being express bus service which operates a portion of its route without stops. Operational or capital transit improvements can have significant impacts on the amount of transit ridership. Strategies to improve transit operations include *signal preemption, service enhancement and expansion, transit service quality, transit coordination, marketing, bus bypass ramps, bus lanes,* and *transit information systems.*

i) *Ottawa-Carleton, Ontario, Canada:* (1990 pop – 313,987); Bus-Transitway (Bus Roadway); $420 million; Federal, Regional operations and capital, Reserves, Passenger fares; 265,000 people ridership daily; elements include 21 mainline routes, 79 routes during peak hours only, 24 stations, fixed routes; in 1978 it was decided that a transitway would convince motorists that there is a better way to commute besides their personal automobiles and the system was completed in 1996; without the transitway, the buses would be required to use the general purpose roadways, which are congested.

ii) *Portland, OR:* (1990 pop – 1,515,452); Portland Transit Mall; $15.8 million; Federal, state and local; ridership not available; elements include 32 shelter TV kiosks, 8 information kiosks, 13 drinking fountains, 209 historic street lamps, widened brick sidewalks, 11 works of art, 5 fountains, 287 London plane (Sycamore) trees (transit mall trademark), and 36 banner poles; the transit mall development removed 308 curbside parking spaces and compensated by building two public parking garages with 1,300 parking spaces; part of a $1.3 billion redevelopment of the downtown area with results that now 50% of people who work downtown take public transportation, buses or light rail.

iii) *Pittsburgh, PA:* (1990 pop – 2,394,811); Bus-East Roadway Extension; $326.8 million; Pittsburgh Turnpike Commission and City of Pittsburgh; 30,000 weekday ridership; elements include over 900 buses; the fixed guideway is exclusive for buses, but allowances are made for emergency vehicles and private bus companies. a significant amount of development has occurred around the busway.

iv) *Bremerton, WA:* (1990 pop – 189,731); Public Bus-Preemption Signals; $4.5 million for start-up cost of entire preemption system; Federal and State; 14,114 passengers daily ridership; elements include 50-60 intersections with preemption and 40 fixed bus routes; integrated vehicle location system allows on-board computer to activate preemption at an intersection when the bus is running late; public's perception is changing regarding buses being slower than personal automobiles.

E.2 <u>Light and Commuter Rail</u>: the fixed nature of rail transit routes somewhat limits them to dense population and activity centers. The functional service areas around the fixed routes are limited to the distance people are willing to travel, by walking or some other means, to a rail transit stop. *Light rail* refers to rail cars that operate on electric power received from an overhead cable, or through the rail system. Typically they are manned by an onboard driver, travel in small groups, and often share the right-of-way with vehicular traffic. *Commuter light rails*, on the other hand, tend to be bi-level cars powered by diesel locomotives. Typically commuter systems may travel between metropolitan areas and stop less frequently than do light rail systems. Rapid growth of businesses and housing can be observed in areas adjacent to transit rail systems.

i) *Sacramento CA:* (1990 pop – 1,418,220); Sacramento Regional Transit District; $350 million implementation and $13.95 million operating cost in 1995; City of Sacramento, Sacramento County, Sacramento Area Council of Governments, and the State of California; primary service includes 36 light rail cars and 18.3 miles of track; 27,500 riders per weekday.

ii) *San Diego, CA:* (1990 pop – 2,498,016); San Diego Trolley Inc.; $552 million (as of 1998); Metropolitan Transit Development Board; primary service includes 123 vehicles and 40 miles of track; 70,000 riders per weekday.

iii) *St. Louis, MO:* (1990 pop – 2,492,348); Metrolink; $420 million (as of 1998); Bi-State Development Agency; primary services includes 31 light rail cars, 17 miles of track and 18 stations; ridership not available.

iv) *Portland, OR:* (1990 pop – 1,515,452); MAX light rail system; $1.6 billion; Federal Transit Authority; FHWA, Oregon DOT, the Cities of Beaverton, Hillsboro, and Portland, and the Counties of Multnomah and Washington;

primary services include 33 miles of track, 46 stations, 72 light rail cars, and a bicycle and ride program; with the creation and expansion of the light rail system, the City of Portland has been able to avoid the expansion of any roads in the downtown area for 20 years; ridership unknown.

v) *Dallas/Fort Worth, TX:* (1990 pop – 4,037,282); Dallas Area Rapid Transit—Light and Commuter Rails; $928.5 million (construction), $27 million light rail operating for FY 1997, $5.0 million commuter rail operating cost for FY 1997; City of Dallas and 12 suburban cities; primary services includes 40 light rail cars traveling 20 miles of light rail track and 13 commuter rail cars traveling 10 miles of commuter track; 35,000 daily ridership for light rail.

E.3 <u>Multimodal Facilities</u>: a multimodal facility is a transfer point at which various modes of travel converge, including automobiles, trains, buses, airports, paratransit shuttles, taxis, bicycle, and pedestrians. Such convergence serves public transportation passengers who are serviced better and the area surrounding the facility experiences economic growth. Many multimodal facilities operate from renovated, preexisting rail facilities, which often include various auxiliary services, e.g., gift shops, conference rooms, and restaurants.

i) *Baltimore, MD:* (1990 pop – 2,382,172); Baltimore-Washington International (BWI) Amtrak Rail Station; $400,000 annual cost; Amtrak; primary services include Amtrak High Speed Rail, Maryland Rail Commuter (MARC), Maryland Aviation Administration Airport Shuttles, Baltimore Central Light Rail, Local Taxi and Limousine Service; 485,000 annual ridership on MARC to and from BWI Airport Station, 147,220 on Amtrak, BWI airport serves 8.696 million passengers per year.

ii) *Battle Creek, MI:* (1990 pop – 429,453); Battle Creek Transportation Center; $2.127 million for design and construction; Battle Creek Transit and the City of Battle Creek; primary services include Amtrak, Greyhound and Indian Trails Bus Service, Battle Creek Local Bus Service, Taxi and Parking; 51,542 annual ridership on Amtrak arriving and departing in 1993; project has helped revitalize the Battle Creek downtown area.

iii) *Meridian, MS:* (1990 pop – 41,036); Union Station Multimodal Transportation Center; $5.016 million; City of Meridian and FTA; primary services include Meridian Transit System, Passenger and Commercial Rail, Inter-City bus, Paratransit Airline Shuttles, and Local Taxi Service; ridership not available; an estimated $8 million of private development has occurred around the center as a result of the renovated facility.

iv) *Gallup, NM:* (1990 pop – 19,157); The Gallup Cultural Center; $2.0 million (construction); primary services include Amtrak, Local, Regional, and National Bus Service; ridership not available; a variety of services are provided within and outside the center.

v) *Dallas, TX:* (1990 pop – 2,676,248); Union Station; $1.2 million (annual operations); primary services include Amtrak, Dallas Area Rapid Transit (light and commuter rail, bus, and paratransit), and local taxi service; ridership not available.

F. EMPLOYER TRIP REDUCTION STRATEGIES

F.1 Compressed Work Week: employees can commute only 3 or 4 days per week when employers allow a compressed work week. This relieves congestion. The compressed work week is generally more viable for employers that have very large numbers of employees at one facility or office. Another alternative is flextime, which allows employees to vary their times for beginning and ending work as long as the hours are within guidelines set by the employer. Staggered work hours are similar to flextime except that it applies to groups of employees rather than individuals.

i) *Princeton, NJ:* (1990 pop – 325,824); Educational Testing Services; no operating cost; 700 employees participate; employees work 37.5 hours per week and can choose either a 12.5 hour/3days or 9.5 hours/3 days plus one 9 hour day; employees indicated that the program cut down on their amount of commuting time. After one year of operation, 30% of the employees switched to the program; of these, 93% preferred the four-day week.

ii) *San Antonio, TX:* (1990 pop – 1,324,749); United Services Automobile Asso.; costs quoted as none; 12,000 employees participate; employees can work a four-day work week and spread those 4 days among any of the seven days of a calendar week. Employees can also work 4-, 5-, and 6- day work weeks of varying hours. Employees reduced commuting costs by 20%.

F.2 Telecommuting: certain tasks can be performed at an employee's home or alternate work site on a personal computer and communicated outside via a telecommunications network. Larger metropolitan areas are using the telecommuting concept for the development of centralized telework centers. These centers still require a commute by the employees, but the commute times and distances can be significantly reduced.

i) *Irvine, CA:* (1990 pop – 2,410,688); Packard-Hughes Interconnect (formerly Hughes Electronics); cost not available; 60 employees participated in a pilot program; employees participating had an average reduced driving distance of 60 miles per week.

ii) *Bellevue, WA:* (1990 pop – 2,033,128); Washington State Telework Center; $135,000 setup cost; participation not available; center setup in 1991 provided telecommuting workstations for employers and their employees living in the Seattle and Bellevue area. These employees had a commute of one hour or more. The center saved telecommuters a total commuting distance of 60,000 miles annually.

iii) *Redmond, WA:* (1990 pop – 2,033,128); City of Redmond; $4,500-$7,500 setup costs; center set up as pilot project had 10 telecommuters who eliminated 450 commute miles and 35 commute hours per week.

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APPENDIX D-1

ARIZONA CONGESTION CONFERENCE AND WORKSHOP: PRE-CONFERENCE WHITE PAPER

Congestion Mitigation Resources & Strategies for Arizona's State Highway System

Pre-Conference White Paper

March 5, 2002
Conference and Workshop
Phoenix, Arizona

by

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March 2002

Research Project SPR 542

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A. Introduction and Background

The purpose of this paper is to introduce this ADOT research project and highlight its preliminary findings as well as present the key objectives of the March 5, 2002 conference and suggested discussion topics for the afternoon workshops.

1. Purpose of Research

Arizona's population growth continues to task the State's transportation facilities at a rate exceeding available capacity, causing continuously increasing congestion, particularly in the Maricopa and Pima Counties but also in and around Flagstaff, Yuma and along portions of rural corridors. As congestion on the State's rural and urban highways is expected to worsen with time, more focus must be directed towards developing tools to help ADOT and other public agencies in measuring, predicting, and remedying congestion. **The main goal of this research is to develop a tool chest of practical strategies to help solve Arizona's urban and rural mobility and congestion problems as they arise in the long-term future.**

A key factor in the long-term success of this statewide effort is building consensus among the Arizona's transportation stakeholders on the issues of congestion definition, measurement, and resolution. This project will strive to answer some basic questions, including:

- How is congestion defined and measured in Arizona today?
- Where does congestion typically occur in Arizona and how big of a problem is it?
- Where can congestion be expected to occur in the future?
- What is the threshold of system breakdown?
- What are the costs of congestion?
- What are the urban and rural congestion issues?
- What solutions exist or will soon become available?
- What are appropriate, valid mitigation performance measures?
- Is congestion inevitable?
- Can we "build our way out" of congestion?

2. Research Scope

This study will review congestion issues on Arizona's rural and urban highways and current congestion definitions, policies, measurements, mitigation practices, and deployed systems used by agencies responsible for traffic operations on the State's highways. A global literature review and interviews of practicing transportation professionals and researchers in the state and throughout the country will be conducted. The findings will be used to propose an acceptable definition of congestion on Arizona's highways and provide an analysis of practical methods of measuring congestion and its impacts. Recommendations of this research will become a resource in the development of ADOT's Long Range Transportation Plan.

The final phase of this effort will begin building a tool chest of congestion mitigation solutions most suitable for implementation in Arizona. Advantages of each mitigation strategy or method, along with a high-level comparative benefits analysis, will be provided to support future planning efforts. The study will recommend strategies best suited for dealing with Arizona's congestion in the long term.

3. Research Team and Other Participants

This research effort is being conducted by a team of local transportation professionals familiar with Arizona's congestion issues and well-known transportation researchers.

Team Member	Agency
Andrew Kolcz – Consultant Project Manager	Bucher, Willis & Ratliff Corporation
Craig Roberts	Northern Arizona University
Shawn Turner	Texas Transportation Institute
Tim Lomax	Texas Transportation Institute
Robert Mickelson	Independent Consultant
Sharon Hansen	PBS&J
Stephen Owen – ADOT Project Manager	Arizona Transportation Research Center

The study is championed by Tim Wolfe (ADOT Transportation Technology Group) and managed by Steve Owen (Arizona Transportation Research Center, ADOT). A Technical Advisory Committee (TAC) provides project guidance and direction. The TAC has taken an active role in this research. Representing a broad cross-section of public agency interests, the Committee includes practicing transportation planners, traffic engineers, and management.

Technical Advisory Committee	
Team Member	**Agency**
Tim Wolfe (Project Champion)	ADOT Transportation Technology Group
Victor Mendez	ADOT Director / Core Team
David Jankofsky	OSPB / Core Team
Dale Buskirk (John Pein)	ADOT Transportation Planning
Tom Parlante	ADOT Traffic Engineering
John Louis	ADOT Roadway Design
Tom Buick (Mike Sabatini; Dave Wolfson)	Maricopa County DOT
Mark Schlappi	Maricopa Association of Governments
Paul Casertano	Pima Association of Governments
Frank McCullagh	ADOT Asset Management
Ed Stillings	Federal Highway Administration

4. Anticipated Products

This research will provide a discussion of common definitions of urban and rural congestion used in Arizona and throughout the United States; analysis of ADOT's current congestion mitigation goals, practices and plans; a database of mitigation methods; analysis of mitigation impacts, and an evaluation of relative merits of candidate strategies for Arizona. The main outcome of the project will be a tool chest of congestion mitigation solutions most suitable for implementation in the state.

B. Summary of Study Findings to Date

This project was kicked off on January 7 of this year. The following sections briefly summarize the key findings of the last two months of research.

1. Congestion by Location Type

Location is a major consideration in determining congestion characteristics. At least four location types must be considered in defining congestion in Arizona. These are high-density metropolitan areas, smaller urban areas, prevalently rural environment, and activity centers.

a. Metropolitan Area Congestion

In Arizona, this means the Tucson and Phoenix metropolitan areas. Highways in these two cities typically provide full or partial access control. Commonly accepted definitions of congestion in those areas utilize average travel speed and delay. Highway congestion is typically observed daily during peak travel periods, when demand approaches capacity and traffic flow may become unstable due to incidents. Consistently longer travel times during the AM and PM peak hours are anticipated and generally tolerated by motorists. Congested levels on high volume highways can also be measured in terms of vehicle headway and lateral friction. Close spacing between vehicles leads to driver frustration, blocked views, and promotes accidents.

Non-peak hour congestion is often unanticipated and less acceptable to the highway user. Examples include localized congestion caused by inefficient intersections, construction zones, slow-moving vehicles, and accident delays not associated with the expected commute time delays. Metropolitan area congestion occurs year around.

b. Urban Area Congestion

Similar to large metropolitan areas, average travel speed and time delay can be used as the key indicators of congestion; however, travel delays are often less severe due to usually shorter trip lengths. State Highways (other than Interstates) typically do not have substantial access control. Here, highways often function as primary arterial streets with congestion resulting from side friction due to frequent intersections and driveways. Pedestrians, bicycles, and parked or stopped vehicles (such as buses) are factors contributing to urban congestion, which may also be highly seasonal due to recreational traffic and winter time visitors.

c. Rural Congestion

Congestion on rural segments of Arizona's highways can result from a variety of conditions. In some rural corridors, vehicular demand approaches the metropolitan levels of lane capacity. High densities of trucks and recreational vehicles contribute to a strong perception of congestion although average travel times and speeds may not be materially affected. Slow-moving vehicles, coupled with limited passing opportunities due to poor roadway geometry or high traffic volumes, can cause considerable reduction in speed, delays and even accidents. Construction zones can result in miles of reduced capacity and speed, causing or contributing to highway congestion. Emerging urbanized areas along State Highways lead to increased side friction because of intersections and driveways. Accidents along rural highways may lead to hours of delay due to limited or non-existent alternative routes, a situation frequently encountered in Arizona.

d. Activity Center Congestion

Congestion can be associated with specific activities on or adjacent to highways. Processing time for vehicles at border crossings can be substantial. Access to and egress from State Highways for high attendance events may lead to congestion on the highway. Recreational or commercial destinations adjacent to State Highways can result in localized congestion. Industrial centers near highways can produce substantial numbers of slow moving heavy vehicles entering, leaving or crossing a State Highway, causing congestion.

2. Performance-based Approach to Congestion Mitigation

The recommendations of this study will feed into the ongoing development of ADOT's new performance-based State Transportation Plan. To facilitate the practical application of the study recommendations, this research is being structured as follows:

a. The congestion performance factors will be divided into four or more location categories, including metropolitan, urban, rural, and activity center. Congestion performance goals will be established for each category such as eliminating or reducing congestion in some locations or mitigating the adverse effects of congestion where it cannot be substantially reduced.

b. A variety of system variables and performance indicators related to congestion will be identified for each of the location categories. These may include capacity, travel delay, vehicle mix, work zones, side friction, accidents, vehicle processing, roadway geometry, adjacent land use, and seasonal traffic differences, to name just a few.

c. Quantifiable congestion performance measures will be identified for each selected indicator. Data must be relatively easy to obtain and interpret for each measure to facilitate the evaluation of congestion-based performance of individual highway segments and entire corridors. It is important to note that performance measure literature distinguishes between two types of measures: output measures and outcome measures. Output measures include, for example, miles of work zone and number of intersections with traffic control and relate to things that transportation agencies do in pursuit of outcomes. Outcome measures are related to what the traveling public actually wants, such as high travel speed and fewer accidents; outcome is the end result of output.

Performance measures must be clearly understandable to all target audiences. These include the general public and elected officials who may ultimately have to make the final decision for implementing some mitigation measures.

d. Congestion mitigation strategy or strategies will be identified for each performance measure. The benefits relative to cost of each strategy should be quantifiable and comparable with other strategies. Examples of congestion mitigation strategies include adding capacity, increasing system throughput with elements of intelligent transportation systems (ITS), car pool lanes, promotion of alternative travel modes, land use planning, travel demand management, improvements to vehicle processing at border crossings, geometric improvements, vehicle separation and incident management.

It is anticipated that congestion mitigation plans will follow this research effort. In these plans, performance objectives would be established for system segments and the present and projected performance of each segment would be evaluated first without application of congestion mitigation measures. Mitigation measures would then be chosen from those identified through this research and their effectiveness in achieving the performance objectives and implementation feasibility would be evaluated. Final mitigation measures would than be selected for inclusion in the plans for each highway segment or corridor. Some measures could be selected for use on an entire location category or the whole system while others would have segment application only.

3. Location Specific Evaluation

The TAC has determined it is beyond the scope of this research project to make location-specific evaluations of the effectiveness of identified mitigation strategies. Location-specific evaluations require substantial amounts of field data and therefore are more appropriate for a systematic evaluation of the State Highway System segments or specific improvement projects. Such evaluations may be performed through a separate project. This study will identify data that will be needed to appropriately evaluate the effectiveness of each of the recommended mitigation strategies.

4. Supply and Demand Side Mitigation Strategies

This study will review both supply and demand side congestion mitigation strategies. **Supply side** congestion mitigation strategies increase the capacity of the transportation infrastructure to meet transportation demand through system expansion and management. Expansion of the transportation infrastructure can mean new roads, more lanes on existing roads or increased supply of alternatives to automobiles and trucks, such as buses and rail. Management involves more efficient use of existing infrastructure through means such as ITS, Freeway Management Systems (FMS), interconnecting and coordinating traffic signals, intersection improvements, access control, car pool lane preferences, improved incident response, and improved vehicle processing.

Demand side congestion mitigation relates to strategies that reduce demand for transportation capacity and includes congestion pricing, parking restrictions, land use controls, and employer travel reduction programs. Supply side congestion mitigation is usually more popular than demand side mitigation, but to effectively deal with congestion in the long run, both approaches need to be considered.

5. Review of Standard Practices by Arizona Agencies

Fifteen key personnel from various Arizona agencies were asked to fill out a questionnaire designed to elicit responses to the basic questions outlined in the Introduction. All respondents agreed that congestion represents a very significant issue in Arizona with congestion mitigation being placed near the top of everyone's priority list. ADOT allocates large funding for mitigating congestion that include capacity expansion to accommodate the existing demand as well as other congestion reduction strategies.

The respondents report that while motorists clearly do not appreciate congestion, little has been done in Arizona to survey customer satisfaction with the State's transportation system. Thus there is no metric to gauge customers tolerance levels versus congestion. One public opinion survey of transportation issues conducted by ADOT (ATRC) in the late 1990's identified congestion as a significant issue.

The majority of the respondents relate the definition of congestion to the Highway Capacity Manual (HCM) Level of Service (LOS), with lower LOS indicating more congested conditions. Congestion is normally considered to occur at LOS D or lower. ADOT has a goal of LOS B or better statewide with LOS D or better in the metropolitan areas. There is a strong view that LOS measure should differ between urban and rural areas. LOS D is suggested as acceptable for urban areas and LOS C for rural highways. Level of service E or F is typically used as the threshold where the system starts to breakdown, with threshold levels varying by location. Breakdown threshold at intersections could be the overriding factor of system breakdown, typical in highly urbanized areas. It is important to note that some agencies do not have a formal definition of congestion.

Other measures of congestion used in the urbanized regions of the state include average delay per vehicle, visual observations of traffic queue lengths at major signalized intersections, and correlation of average daily traffic (ADT) and LOS.

The issue of distinguishing rural vs. urban congestion in Arizona received little overall attention from the respondents, possibly indicating that the topic of rural congestion is not traditionally in most agencies' focus. Those who commented on this issue noted that rural congestion is often related to through traffic (i.e., traffic passing through a community) and to events or popular tourist locations (e.g. the Grand Canyon or the Painted Desert). In addition, congestion in rural areas may occur during different time periods and days of the week, e.g. on Friday afternoons or Sunday evenings when travelers leave town or return from weekend trips. Urban congestion on the other hand is typically related to the AM and PM peak hour travel periods.

References were made to the Maricopa Association of Governments' (MAG) areawide congestion studies. It was pointed out that the MAG studies did not quantify the cost of congestion. A relevant study conducted by the Texas Transportation Institute (TTI) for the Phoenix urban area was also mentioned. The TTI study quantified the delay and fuel consumption caused by congestion delay and value of lost time. References were also made to the Congestion Management System Report and the Long Range Plan.

Most of the respondents were not aware of data collection specifically relating to congestion. Some mentioned the data collected by the Phoenix Freeway Management System (FMS) which include traffic volumes, occupancy and speeds. Others mentioned turning movements, queue lengths and approach delay at intersections.

In response to the question: *What is currently being done and what is planned to mitigate congestion?* survey participants mentioned continuous use of the tools built into the FMS such as Variable Message Signs (VMS) and ramp meters; promoting the use of alternative modes of transportation; traffic signal synchronization; network expansion including alternate routes; improved agency communications; more detailed studies of congestion; intersection improvements; increased funding for congestion mitigation programs; coordination of land use planning with transportation infrastructure improvements; adding capacity to highways and at intersections; truck-only lanes; light rail system; expansion of the bus transit system; improved signing and striping at minor intersections; city-to-city signal progression; HOV program; improved responses to collisions; and freeway service patrols.

There was wide variation among respondents in how their agencies evaluate and select mitigation measures. Measures cited included system evaluation through modeling; using perceived customer tolerance levels; measures based on traffic volumes; observed congestion; accident experience, and existing and planned land uses.

About half of the respondents did not comment on what might be valid mitigation performance measures. Some cited amount of travel to avoid congested areas; average delay time; customer feedback; reducing delay per vehicle; reducing accident rates; stopped delay at intersections; average speed point-to-point; number of stops in a given trip; LOS; ADT; one-hour peak volume; and travel time.

In response to increasing congestion, some agencies are developing their own traffic monitoring systems. Congestion problems are typically reviewed on a case by case basis, district by district, and community by community. Often the word "congestion" is not used but many agency staff is constantly monitoring the street system to identify and try to remedy congestion. ADOT TPD alone has traditionally been tasked with the systematic planning of improvements to reduce congestion. The ISTEA-mandated and now non-mandatory Congestion Management System program was never really "turned-on" in Arizona. MAG and PAG are administering the only monitoring programs.

The majority of the respondents felt that congestion was inevitable. One pointed out the issue of latent demand for travel, which is not easily quantifiable, but of such magnitude that it is not cost effective to continue to build enough capacity to satisfy it without congestion. Most respondents did not support the notion that we can "build our way out" of congestion. Some expressed the need to consider a "big picture" approach to the problem, i.e. to consider other alternatives modes of transport. A few mentioned political will to provide funding for road improvements.

Ongoing air quality, energy conservation, and land use planning studies in Arizona should be incorporated into the transportation planning process. By working together with our local jurisdictions, communities, and planning together, congestion issues can be tackled more successfully. The idea of interaction between land use planning and transportation system planning is being explored at ADOT. Currently little can be done as each city controls its land use planning and there is no overall champion of this approach. **What we need is a smorgasbord of ideas to pick from.**

Efforts are currently underway through this project to finalize the review of selected planning study reports from ADOT, County, City, and regional planning organizations in Arizona. The project team is reviewing these works, which include the current ADOT State Transportation Plan, with focus on agency measures, goals, plans, and techniques to mitigate and manage congestion on the State Highway System.

6. Industry Survey

The survey of today's body of knowledge and state of the practice in congestion management would not be complete without taking into account the opinions and expertise of industry professionals in other parts of the country. The project team is conducting interviews with transportation practitioners from selected state DOTs, the U.S. DOT, regional governments, university research centers, and private transportation and communications companies.

7. Review of Literature Sources

A search of technical literature has resulted in considerable amount of information relevant to congestion management that is applicable to Arizona. As used here, congestion management means the tools that are available or emerging that will help ADOT and other Arizona public agencies measure, predict, and remedy traffic congestion problems on the State's transportation facilities. However, what is meant by "congestion" is not as straightforward as might first be assumed. In fact, how to actually define congestion is itself a part of this literature search.

a. Metrics: How Do We Measure Congestion?

This section summarizes the major metrics of congestion found in the literature published within approximately the last ten years. Each subsection presents a primary set of metrics that are either a unique source or representative of a type. The metrics mentioned here were selected from the ones that have been used by transportation agencies and found to be useful.

Highway Capacity Manual Methods for All Facility Types

The traditional standard for traffic engineering studies for most federal, state, and local agencies is the *Highway Capacity Manual (HCM)* (TRB, 2000). The fourth and current edition of the HCM was issued in 2000 and is often called "HCM 2000". This edition introduces many revised or expanded procedures for calculating *capacity* and *level of service* and provides these useful definitions:

- *Capacity*: the capacity of a facility is the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions.

- *Performance Measures*: each facility type that has a defined method of assessing capacity and level of service [in the HCM 2000] also has performance measures that reflect the operating conditions of a facility, given a set of roadway, traffic, and control conditions. For each facility type, one or more of the stated performance measures serves as the primary determinate of level of service. This LOS-determining parameter is called the service measure or sometimes the measure of effectiveness (MOE) for each facility type.

- *Level of Service (LOS)* is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.

By definition, LOS is based on different service measures for different facility types. In the HCM 2000, LOS is based on: (1) travel speed for *urban streets*, (2) control delay for *signalized intersections*, (3) control delay for *stop controlled intersections* (for each minor movement), (4) space (the inverse of density) for *pedestrian walkways and sidewalks*, (5) number of passing and opposing events for *exclusive and shared bicycle paths*, (6) control delay for bicycles at *signalized intersections* (per movement), (7) bicycle travel speed for *bicycle lanes on urban streets*, (8) percent time-spent-following and travel speed for Class I (high speed) *two-lane highways* but only percent time-spent-following for Class II (lower speed) two-lane highways, (9) density for *uninterrupted multilane highways*, and (10) density for *basic* and *ramp merge/diverge freeway segments* and speed for *weaving freeway segments*.

It is important to note that the **HCM 2000 methodologies often do not apply to oversaturated conditions, i.e., during congestion**. The HCM 2000 does not specifically define *congestion* but instead leaves it to the analyst to determine what levels of service are acceptable and unacceptable for the application being considered.

1998 MAG Regional Congestion Study

The *1998 MAG Regional Congestion Study* is archetypal of metrics relying primarily on HCM methods. The study used the 1995 Update of the third edition of the HCM to define LOS for the major intersections and freeway segments within their study area, i.e., greater metropolitan Phoenix. The authors of this study state:

> "Intersections and freeway segments operating at LOS A through C are usually considered to be operating 'under capacity.' LOS D is considered 'near capacity,' and LOS E and F are considered 'over capacity.' LOS E and F indicate levels of traffic congestion and delay that are generally unacceptable to most drivers in major metropolitan areas."

The MAG study used six performance measures for freeways (vehicle volumes: 24-hour volumes, AM and PM peak hour volumes; 24-hour truck volumes; AM peak period LOS; AM peak period duration of LOS F; PM peak period LOS; and PM peak period duration of LOS F). Four performance measures for HOV usage were used (AM peak hour HOV lane volumes; AM peak period HOV lane LOS; PM peak hour HOV lane volumes; and PM peak period HOV lane LOS). The MAG study also considered six performance measures for major intersections (AM peak hour LOS; AM peak period duration of LOS F; AM peak hour temporal location; PM peak hour LOS; PM peak period duration of LOS F; and PM peak hour temporal location).

Performance Measures on the Example of the Seattle Metropolitan Freeway System

In the Seattle metropolitan area, a freeway usage and performance report was prepared that presented an overview of the level of traveler usage and travel performance on the principal urban freeways in the central Puget Sound area. The researchers used five performance measures for freeway corridors:

- *traffic congestion levels at locations along the corridor by time of weekday*,
- *congestion frequency defined as the likelihood that significantly congested traffic will occur at a particular location and time of weekday,*

- *average trip travel times estimated for 18 hypothetical trips (9 routes, traveling in both directions) that traverse one or more corridors, for a range of trip start times throughout a 24-hour weekday,*
- *90th percentile travel times (i.e., 90% of time travel would take less than this time) estimated for the same 18 hypothetical trips and start times as used for average trip travel times [the difference between the average trip time and the 90th percentile trip time can be thought of as an indicator of variability or reliability for the trip], and*
- *frequency of "slow" trips estimated the percentage of times that the average overall trip speed for the 18 hypothetical trips would be below 35 mph for a given start time.*

While the corridor performance measures give an overview of system performance, the research used three different performance measures, averaged from data for the entire year, to evaluate performance at specific sites:

- *average traffic volume at the site by time of weekday,*
- *average speed at the site by time of weekday, and*
- *frequency of heavy congestion at the site measured as the percent of time that congestion will be encountered at a time of weekday.*

The occupancy requirement for all High Occupancy Vehicle (HOV) lanes on the Seattle metropolitan freeway system is at least 2 occupants. The research used two performance measures, averaged from data for the entire year, for HOV usage:

- *number of vehicles traveling per lane per hour by time of weekday, on both the general purpose (GP) and the HOV lanes, and*
- *number of persons traveling per lane per hour by time of weekday, on both the GP and HOV lanes.*

b. Technologies: How Do We Collect Congestion Data or Estimate It?

Intelligent Transportation Systems (ITS) hold the promise of reducing recurring congestion (due to capacity shortfall) and nonrecurring congestion (due to incidents). These systems are evolving and depend on constantly improving technology. Other strategies (for example telecommuting) also depend on harnessing new technologies or adapting them to transportation purposes from other fields. The focus of this part of the research is on referencing literature that discusses technologies that are currently being used to manage congestion and to give a small sampling of recent research that shows promise.

Several Federal Highway Administration sponsored programs address the need for accurate and frequent traffic flow sampling as well as to expand the types of traffic flow descriptors. These programs provide information on the theory and application of non-intrusive sensors; recent findings on traffic management tactics, algorithm descriptions and performance; and data requirements in support of incident detection, ramp metering, traffic signal control, traveler information services, electronic toll collection, commercial vehicle electronic clearance, hazard warning, data reporting, and archival needs.

The literature review task also identified valuable practical information on technologies for real-time detection of traffic congestion, adaptive traffic control systems, field measurement and estimation of congestion. The study's final report will include a detailed review of the literature sources.

c. Strategies: How Do We Mitigate and/or Manage Congestion?

In many urban and rural communities increasing levels of traffic congesting have turned once easy trips into nightmares. The lack of accurate and timely public transportation information and services has discouraged drivers from considering options other than driving alone. People are turning to community and state officials for solutions. And there are ways of dealing with traffic congestion problems. Some actions can be used individually, while others require extensive cooperation by several public and private sector groups. Some actions focus exclusively on changes to the transportation system, while others deal with changes to land development procedures. Some strategies involve adding capacity to highway and transit systems to accommodate passenger demand, while others attempt to change the characteristics of demand itself, e.g., by encouraging ridesharing. Regardless of what type of action is considered, those who are dealing with transportation problems need to have information on different strategies that can be used to deal with congestion.

A great amount of information about congestion mitigation strategies exists in countless resources, which can cause a potential overload when gathering such material. Fortunately, the topic of congestion has been at the forefront of the research being conducted by the Texas Transportation Institute (TTI). Several information sources developed by TTI are presented here for reference.

NCHRP Report 398, *Quantifying Congestion, Volume 1, Final Report* (Lomax, et al., 1997), focused on methods to measure congestion on roadway systems to develop methods that are both reliable and understandable; can apply to a route, subarea, corridor, or entire urban region; can relate to simple and easy-to-obtain parameters; and can be forecast. **The metrics of volume and capacity, which traditionally have been used to evaluate new infrastructure, were found inadequate to address the greater set of solutions being deployed today.** These solutions require measures that capture the effects of congestion mitigation actions beyond their volume and capacity impacts.

Authors argue that the needs surrounding congestion and mobility are changing and multimodal analyses will play an increasing role. They point out that while the overwhelming majority of agencies incorporate the LOS concept as a measure of congestion, there is no consensus regarding the LOS range corresponding to the threshold, or beginning, of congestion. They propose a system that solves the problems of transportation professionals and others for measurement techniques while being cognizant of data collection concerns. Key to their system are measures related to travel time and speed; these serve professionals well while being readily understood by the public. These measures are appropriate for a broad range of contexts: (1) evaluating future conditions, (2) changes due to construction, operational improvements, and management alternatives, (3) policy or land use decisions, and (4) a wide range of person and freight movement analyses.

Lomax, et al. identified two definitions of congestion in their research that respond to this broad range of contexts. Both focus on the <u>effect</u> of congestion. The authors used these definitions to develop a program of congestion measurement techniques.

- *Congestion* is travel time or delay in excess of that normally incurred under light or free-flow travel conditions.

- *Unacceptable congestion* is travel time or delay in excess of an agreed-upon norm. The agreed-upon norm may vary by type of transportation facility, travel mode, geographic location, and time of day.

The report developed the critical concept of defining an acceptable level of congestion. An acceptable travel speed or travel time will be different in urban and rural settings, and within each of these settings, will be different on freeways/arterials and lower-class streets. To complement their definitions of congestion, the report also defined *mobility* and *accessibility* somewhat differently than they have traditionally been defined.

- *Mobility* is the ability of people and goods to move quickly, easily, and cheaply to where they are destined at a speed that represents free-flow or comparably high-quality conditions.

- *Accessibility* is the achievement of travel objectives within time limits regarded as acceptable.

While the report suggests there is probably no single value that will satisfactorily capture travelers' concerns about congestion, they propose that four components can interactively do so. The authors define these four components, *duration, extent, intensity,* and *reliability*, relative to the type of system being examined in a useful matrix, which is reproduced here in Table 1 (Appendix).

Proposed measures of congestion are summarized in Table 2 (Appendix) as are recommendations on how to apply them at various scales and for various types of analyses. The report details the application of these measures to several typical analyses using examples.

C. Conference and Workshop

1. Purpose

The primary goal of the March 5 conference and workshop is to help understand the ways in which congestion is effectively defined, measured, and dealt with and to begin building consensus around the issue of congestion in Arizona. The workshop's key objective is to begin a statewide discussion to help resolve the issue of the best congestion definitions and performance measurements for ADOT to employ. The workshop will offer an opportunity for Arizona's' transportation stakeholders to share their thoughts and experiences on the subject of traffic congestion. Through presentations and discussion, regional practitioners and national experts will provide perspectives on congestion management practices in Arizona and elsewhere in the country.

2. Format

The morning session will deal with presentations from invited speakers. Topics cover both urban and rural perspectives and experience on congestion problems and mitigation strategies. The afternoon session will be devoted to finding solutions for congestion in Arizona. Discussions will take place in workgroups of approximately ten participants in each group. Five facilitated discussions groups are planned. Each workgroup will be assigned a major topic to deliberate and at the end of the discussion the facilitators will summarize the outcomes. Details of the sessions are shown in the meeting agenda (see Appendix).

3. Expected Workshop Results

The conference is expected to promote a better understanding of the significance of the congestion problem in Arizona and kickoff a statewide effort to develop relevant definitions, measurement methods, and effective mitigation strategies. Workshop participants will benefit by learning how agencies inside and outside the State are addressing congestion. Through this study, the participants will become more attuned to what ADOT is doing to reduce congestion on the State Highway System. It is hoped that consensus or at least a common direction will be initiated on Arizona's basic definition, measurement and resource questions on congestion mitigation.

D. Topics for Workshop Discussions

The following five general topics are proposed for the afternoon workshops (see conference Agenda). Each table will be assigned a single topic to kickoff the discussion. Additional and more detailed topics and subtopics will be provided as handouts; several additional topics are included in the Appendix.

1. Definitions of Congestion
2. Congestion Mitigation Strategies (supply and demand sides)
3. Techniques for Evaluating and Comparing Congestion Mitigation Strategies
4. Rural congestion
5. Institutional Issues and Policies

Appendix

Table 1: Overview of Methods to Measure Congestion Components

Table 2: Measures of Congestion

Workgroup Discussion Topic: Techniques for Evaluation/Comparison of Strategies to Mitigate Congestion

Table 1: Overview of Methods to Measure Congestion Components

Congestion Aspect	System Type		
	Single Roadway	**Corridor**	**Areawide Network**
Duration is the amount of time congestion affects the travel system.	Hours that facility operates below acceptable speed.	Hours that facility operates below acceptable speed.	Set of travel time contour maps; "bandwidth" maps showing amount of congested time for system sections.
Extent is described by estimating the number of people or vehicles affected by congestion and by its geographical distribution.	*Percent* or amount of congested VMT or PMS; Percent or lane-miles of congested road.	*Percent of VMT or PMT in congestion; Percent or miles of congested road.*	Percent of trips in congestion; Person-miles or person-hours of congestion; Percent or lane-miles of congested road.
Intensity is the severity of the congestion that affects travel.	Travel rate; delay rate; relative delay rate; minute-miles; lane-mile hours.	Average speed or travel rate; delay per PMT; delay ratio.	Accessibility; Total delay in person-hours; Delay per person; Delay per PMT.
Reliability is the variation in the other three components.	Average travel rate or speed +/- standard deviation.	Average travel rate or speed +/- standard deviation; delay +/- standard deviation.	Travel time contour maps with variation lines; Average travel time +/- standard deviation; Delay +/- standard deviation.

Source: Adapted from *NCHRP Report 398*; *Quantifying Congestion* (Lomax, et al., 1997)
Footnote: VMT = vehicle-miles of travel; PMT = person-miles of travel.

Table 2: Measures of Congestion

Measure of Congestion	Method of Calculation
Travel Rate (minutes per mile)	$\text{Travel Rate} = \frac{\text{Travel Time (minutes)}}{\text{Segment Length (miles)}} = \frac{60}{\text{Average Speed (mph)}}$
Delay Rate (minutes per mile)	$\text{Delay Rate} = \text{Actual Travel Rate} - \text{Acceptable Travel Rate}$
Total Delay (vehicle-minutes)	$\text{Total Segment Delay} = [\text{Actual Travel Time} - \text{Acceptable Travel Time}] \times \text{Vehicle Volume}$
Corridor Mobility Index (dimensionless)	$\text{Corridor Mobility Index} = \frac{\text{Passenger Volume (persons)} \times \text{Average Travel Speed (mph)}}{\text{Normalizing Value (e.g., 25,000 for streets, 125,000 for freeways)}}$
Relative Delay Rate (dimensionless)	$\text{Relative Delay Rate} = \frac{\text{Delay Rate}}{\text{Acceptable Travel Rate}}$
Delay Ratio (dimensionless)	$\text{Delay Ratio} = \frac{\text{Delay Rate}}{\text{Actual Travel Rate}}$
Congested Travel (vehicle-miles)	$\text{Congested Travel} = \text{Sum of all } [\text{Congested Segment Length (miles)} \times \text{Traffic Volume (vehicles)}]$
Congested Roadway (miles)	$\text{Congested Roadway} = \text{Sum of all Congested Segment Lengths (miles)}$
Accessibility (count/extent of opportunities)	$\text{Accessibility (opportunities)} = \text{Sum of all} \begin{bmatrix} \text{Objective fulfillment opportunities (e.g., jobs)} \\ \text{where Travel Time} \le \text{Acceptable Travel Time} \end{bmatrix}$

Source: Adapted from NCHRP Report 398; Quantifying Congestion (Lomax, et al., 19

Workgroup Discussion

TOPIC: TECHNIQUES FOR EVALUATION/COMPARISON OF STRATEGIES TO MITIGATE CONGESTION

How Do We Define Congestion?

- One source defines traffic congestion as *"the incremental costs resulting from interference among road users."*
- Another source defines congestion by using Levels of Service (LOS), *"Intersections and freeway segments operating at LOS A through C are usually considered to be operating 'under capacity.' LOS D is considered 'near capacity,' and LOS E and F are considered 'over capacity.' LOS E and F indicate levels of traffic congestion and delay that are generally unacceptable to most drivers in major metropolitan areas."*
- Another source defines "congestion" as "*travel time or delay in excess of that normally incurred under light or free-flow travel conditions."* "Unacceptable congestion" is defined as "*travel time or delay in excess of an agreed-upon norm. The agreed-upon norm may vary by type of transportation facility, travel mode, geographic location, and time of day."*

How Do We Choose Among Various Strategies to Mitigate Congestion?

- Choose One-at-a-Time *or* Groups?: Some sources caution that congestion mitigation should not be approached in a piecemeal manner; rather it should be approached with a well planned array of complementary measures implemented as a coordinated program.
- Is a Benefit/Cost Analysis Appropriate?: *ITE Toolbox for Alleviating Traffic Congestion and Enhancing Mobility* points out that the benefits and costs associated with transportation improvements vary by type of improvement, the context in which the project is being placed, and who is defining the benefits and costs. Three cost/benefit categories are listed:
    1. *Private benefits or costs*, i.e., experienced by persons or private firms using facilities.
    2. *Social benefits or costs*, i.e., the sum of benefits or costs to persons.
    3. *Societal accounting*, i.e., account for all impacts on individuals, not just the impacts on those directly involved in some activity.

- How do We Set The Timeframe for Analysis?: Some strategies require different time periods for their full effect to be known. For example, the time frame to evaluate the strategy to synchronize traffic signals along a major arterial is quite short compared with strategies that try to influence demand, e.g., HOV lanes or land use policy shifts.
- What Role Do We Give to Public Involvement?: Should the public input be (a) evaluated as to their response to specific strategies presented to them or (b) be used to perform the actual selection process of which specific strategies to implement?
- Is Comparison As To the Efficacy of a "Given" Strategy Sufficient?: Can an "accepted" strategy be adopted and then subject to evaluations about how to best implement it, e.g., signal synchronization, ramp metering, HOV lanes, etc?
- Can the Experiences of Others Be Considered a Sufficient Analysis/Comparison?: Recently the *Twin Cities Ramp Meter Evaluation* (Cambridge Systematics, 2001) was completed which was an exhaustive evaluation of ramp metering strategies that resulted in specific recommendations as to ramp metering operating principles and methodologies. Can these be adopted in Arizona with only a modest review?

- What Weight Should Be Given to Modes Other Than Highways?: It can be argued that most Arizonan's consider "congestion" to be a roadway problem, which requires a "roadway solution." How do we weigh strategies that involve mode shifts to other forms of travel, e.g., busses, light rail, bicycles, walking, telecommuting? How are such mode shift strategies compared to "highway" strategies?
- Is one "type" of congestion more "important" than another?: How do we compare "rural" congestion and "urban" congestion strategies? How do we compare strategies targeted to address congestion occurring on "urban freeways" with that occurring at "border crossings" with that occurring in "neighborhoods" due to cut-through commuter traffic"?

How Do We Evaluate/Compare Very Different Types Of Strategies?

Some strategies effect *Supply* (e.g., more lanes) and some effect *Demand* (e.g., flextime). Here is a list of some well-known congestion mitigation strategies. How can we compare these "against" one another?

INTELLIGENT TRANSPORTATION SYSTEMS
Incident Management (IM)
Variable Message Sign (VMS)
Ramp Meters
Transportation Management Centers (TMCs)
Freeway Service Patrol (FSP)
Railroad Grade Crossing Warning Systems
Electronic Fare Payment Systems

CONSTRUCTION
Night Construction
Construction and Public Awareness/Relations
Lane Closures

PUBLIC TRANSIT
Bus
Light and Commuter Rail
Multimodal Facilities
Transit-oriented Parking Policies

MANAGING TRANPORTATION DEMAND
Compressed Work Week
Telecommuting
Growth Management
Freight Movement Management
Urban Design
Congestion Pricing
Auto Restriction Zones
Parking Management
Trip Reduction Ordinances
Negotiated Demand Management Agreements

HIGH-OCCUPANCY VEHICLE SYSTEMS
High Occupancy Vehicle (HOV) Lanes (Both on Freeways and Arterials)
High Occupancy Toll Lanes (HOT) and Congestion Pricing (CP)
Rideshare
Park and Ride Facilities

ROAD IMPROVEMENTS
New Highways
Geometric Design
Grade Separations
Reversible Traffic Lanes
Traffic Calming
Access Management
Bicycle/Pedestrian Paths
Traffic Signalization
Intersection Improvements
Express lanes
Border Crossings
Added Single Occupant Vehicle (SOV) Lanes

IMPLEMENTATION, FUNDING, AND INSTITUTIONAL MEASURES
Funding Tied to Strategies
Toll Roads
Public/Private Partnerships
Development Fees
Transportation Management Associations

APPENDIX D-2

ARIZONA CONGESTION CONFERENCE AND WORKSHOP: POST-CONFERENCE WHITE PAPER

Congestion Mitigation Resources & Strategies for Arizona's State Highway System

Post-Conference Summary White Paper

March 5, 2002
Conference and Workshop
Phoenix, Arizona

by

Andrew Kolcz and Virginia Sapkota
Bucher, Willis & Ratliff Corporation

for

Arizona Department of Transportation
Arizona Transportation Research Center

April 2002

Research Project SPR 542

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A. Introduction and Background

On March 5, 2002, Arizona Department of Transportation held a conference and workshop on "**Congestion Mitigation Resources and Strategies for Arizona's State Highway System**" at the Radisson Phoenix Airport Hotel. Conference participants were introduced to the current research on congestion mitigation being conducted for the Arizona Transportation Research Center by the firm of Bucher, Willis & Ratliff Corporation. The objectives of the event included familiarizing Arizona's transportation stakeholders with ADOT's ongoing efforts to study and reduce congestion on Arizona's highways. Each participant received a copy of the Pre-Conference White Paper, highlighting the research project's findings to date.

Details of the morning presentations are outlined in the conference agenda and key points from the presentations are mentioned in Section B of this paper. Summaries of the workshop discussions can be found in Section C. The following text provides further details on the conference and workshop purpose, agenda, participants and research team and Technical Advisory Committee.

Purpose of the Conference and Workshop

The primary goals of the March 5 conference and workshop were to help understand the ways in which traffic congestion is effectively defined, measured, and dealt with, and, to begin building consensus around the issue of congestion in Arizona. The workshop's key objective was to begin a statewide discussion on best congestion definitions and performance measures to be incorporated into ADOT's planning and operations. The workshop provided an opportunity for Arizona's transportation stakeholders to share their thoughts and experiences on the subject. Through presentations and discussions, regional practitioners and national experts imparted perspectives on congestion mitigation practices in Arizona and elsewhere in the country.

It was hoped that the conference would promote better awareness of the significance of congestion on Arizona's highways and kickoff a statewide effort to develop common and relevant definitions, measurement methods, and effective mitigation strategies. Workshop participants benefited by learning how agencies inside and outside the State are addressing congestion. Through this study, the participants would become more attuned to what ADOT is doing to reduce congestion on the State Highway System.

Conference Agenda

The table below shows details of the conference agenda. The conference was kicked off at 8:15 a.m. by Tim Wolfe, ADOT Assistant State Engineer, who is also the project Champion. Participants were then greeted with a warm welcome from the ADOT Director, Victor Mendez. The morning session that followed was devoted to presentations on congestion-related efforts in Arizona and similar efforts and research in other parts of the country. Topics cover both urban and rural perspectives and experience on congestion problems and mitigation strategies.

Lunch time provided an opportunity to exchange ideas and take a break after the information-intense morning presentation. The afternoon session was devoted to finding definitions, measures, and solutions for congestion in Arizona. The discussions took place in workgroups of approximately ten participants in each group. There were five facilitated discussion groups. Each workgroup was assigned a major topic to deliberate, and at the end of the discussion each facilitator provided a summary of the group's outcome. The workshop topics, together with summaries of the workgroup discussions, are described in Section C.

March 5, 2002 Conference & Workshop Agenda

7:30 - 8:15 AM	Registration	Coffee, juice, pastries
8:15 - 8:30 AM	Welcome	Victor Mendez, ADOT Director
8:30 - 9:00 AM	General Concepts for Defining and Measuring Congestion	Shawn Turner, TTI
9:00 - 9:30 AM	Congestion Mitigation Strategies: National Overview	Tim Lomax, TTI
9:30 - 10:00 AM	Performance Based Planning - Linking Congestion Monitoring to Planning and Programming	George Mazur, Cambridge Systematics
10:00 - 10:15 AM	Break	Refreshments
10:15 - 10:45 AM	Regional Congestion Monitoring in Phoenix	Mark Schlappi, MAG
10:45 - 11:05 AM	Congestion Monitoring and Management in Rural Arizona	Rick Powers, ADOT District Engineer
11:05 - 11:25 AM	Other Arizona Regional Perspectives – PAG / Pima County	Charles Hodges, PAG Albert Letzkus, Pima County
11:25 - 11:55 AM	The ADOT Perspective: Planning and Operations	Dale Buskirk, ADOT TPD
11:55 - 1:00 PM	Lunch	Provided
1:00 - 1:15 PM	Study Findings To-Date	BWR Consultant Team
1:15 - 2:15 PM	Workgroup Discussions	Facilitated
2:15 - 2:30 PM	Break	Refreshments
2:30 - 3:30 PM	Workgroup Discussions	Facilitated
3:30 - 4:00 PM	Summary of Key Findings and Next Steps	BWR Consultant Team

Conference Attendees

Fifty stakeholders participated in the conference. Majority of the attendees joined in the afternoon workshop discussions. The following table lists all of the conference participants.

#	First	Last	Organization	TITLE
1	Manny	Agah	ADOT Transportation Tech. Group	Traffic Operations Center Manager
2	Nayan	Amin	Bucher, Willis & Ratliff Corp.	Senior Technical Manager
3	John	Bogert	ADOT / Core Team	Chief of Staff
4	Stuart	Boggs	RPTA - Valley Metro	Manager of Transit Planning
5	Debra	Brisk	ADOT Deputy Director	Departmental Deputy Director
6	Dale	Buskirk	ADOT Transportation Planning Div.	Assistant Director
7	Paul	Casertano	Pima Association of Governments	Transportation Systems Senior Planner
8	Sam	Chavez	ADOT TPD Transit Team	Section 5311 Program Administrator
9	Gerry	Craig	City of Flagstaff	City Traffic Engineer
10	Sharon	Hansen	PBS&J	ITS Program Manager
11	John	Hauskins	ADOT/ Phoenix Maintenance District	District Engineer
12	Don	Herp	City of Phoenix	Deputy Director
13	Mark	Hickman	University of Arizona	Professor of Engineering
14	Charles	Hodges	Pima Association of Governments	Modeling Manager
15	David	Jankofsky	OSPB / Core Team	Manager
16	Sarath	Joshua	Maricopa Assoc. of Governments	ITS Program Manager
17	Andrew	Kolcz	Bucher, Willis & Ratliff Corp.	Project Manager and Team Leader
18	Rachel	La Mesa	Northern Arizona University	Student Research Assistant
19	Dan	Lance	ADOT State Engineer's Office - Valley Transportation Section	Deputy State Engineer
20	Albert	Letzkus	Pima County DOT	Traffic Engineer
21	Tim	Lomax	Texas Transportation Institute	Mobility Analysis Research Engineer
22	John	Louis	ADOT Roadway Engineering Group	Assistant State Engineer
23	George	Mazur	Cambridge Systematics	Transportation Consultant
24	John	McGee	ADOT / Core Team	Chief Financial Officer
25	Victor	Mendez	ADOT Director / Core Team	Departmental Director
26	Bob	Mickelson	Senior Project Advisor	Senior Project Advisor
27	Karen	Mills	ADOT / Core Team	Assistant to the Director
28	Stephen	Owen	ADOT ATRC	Research Project Manager
29	Tom	Parlante	ADOT Traffic Engineering Group	Transportation Engineer
30	Ted	Payne	Pima County DOT	Division Manager, Transport. Systems
31	John	Pein	ADOT Transportation Planning Div.	State and Regional Planning Manager
32	Lisa	Pendrick	ADOT TPD	Vision 21 Liaison
33	Perry	Powell	ADOT Phoenix Construction District	District Engineer
34	Rick	Powers	ADOT Globe District	District Engineer
35	Craig	Roberts	Northern Arizona University	Dir. of AZTrans and Asst. Prof. of Eng'g
36	Derek	Rushing	ADOT / Core Team	Chief Information Officer
37	Virginia	Sapkota	Bucher, Willis & Ratliff Corp.	Transportation Planner
38	Mark	Schlappi	Maricopa Assoc. of Governments	Systems Analysis Program Manager
39	Stacey	Stanton	ADOT / Core Team	Director of Motor Vehicle Division
40	Kim	Stevens	ADOT Aeronautics Division	Program Administrator
41	Ed	Stillings	Federal Highway Administration	Mobility Planning Engineer
42	Jeff	Swan	ADOT / Holbrook District	District Engineer
43	Mary Lynn	Tischer	Transportation Planning Div'n / Core Team	Division Director
44	Shawn	Turner	Texas Transportation Institute	Mobility Analysis Research Engineer
45	Dale	Wachs	City of Prescott	Public Works Director
46	Dave	Wessel	City of Flagstaff	Transportation Planner
47	Ron	Williams	ADOT Construction	Assistant State Engineer - Construction
48	Tim	Wolfe	ADOT Transportation Tech. Group	Assistant State Engineer - Technology
49	Dave	Wolfson	Maricopa County DOT	Senior Analyst
50	Dick	Wright	ADOT / Core Team	State Engineer

Research Team and Technical Advisory Committee

This research effort is being conducted by a team of local transportation professionals together with well-known transportation researchers:

Consultant Team	
Team Member	**Agency**
Andrew Kolcz – Consultant Project Manager	Bucher, Willis & Ratliff Corporation
Craig Roberts	Northern Arizona University
Shawn Turner	Texas Transportation Institute
Tim Lomax	Texas Transportation Institute
Robert Mickelson	Independent Consultant
Sharon Hansen	PBS&J

The study is championed by Tim Wolfe (ADOT Transportation Technology Group) and managed by Steve Owen (Arizona Transportation Research Center, ADOT). A Technical Advisory Committee (TAC) provides project guidance and direction. The TAC has taken an active role in this research. Representing a broad cross-section of public agency interests, the Committee includes practicing transportation planners, traffic engineers, and management.

Technical Advisory Committee	
Member	**Agency**
Tim Wolfe (Project Champion)	ADOT Transportation Technology Group
Victor Mendez	ADOT Director / Core Team
Debra Brisk	ADOT Deputy Director
Terry Trost (David Jankofsky)	OSPB / Core Team
Dale Buskirk (John Pein)	ADOT Transportation Planning
Tom Parlante	ADOT Traffic Engineering
John Louis	ADOT Roadway Design
Tom Buick (Mike Sabatini; Dave Wolfson)	Maricopa County DOT
Mark Schlappi	Maricopa Association of Governments
Paul Casertano	Pima Association of Governments
Frank McCullagh	ADOT Asset Management
Ed Stillings	Federal Highway Administration
Stephen Owen – ADOT Project Manager	Arizona Transportation Research Center

B. Key Points of the Morning Presentations

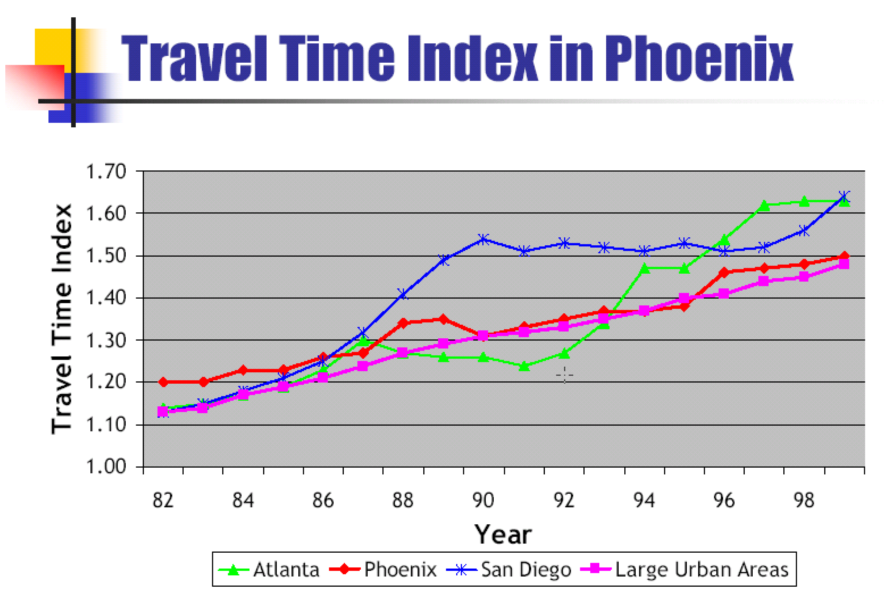
Eight speakers from the Consultant Team, ADOT, and other Arizona transportation agencies were invited to provide highlights on congestion-related efforts in Arizona and similar efforts and research in other parts of the country. Their presentations covered a wide-range of topics from the technical definition and measurement of congestion to the actual state of congestion in Arizona's State Highway System. A brief summary of the presentations is provided below. Each of the presentations can be downloaded at: www.bwrcorp.com/bwrtrp1/conference.htm. Readers are encouraged to contact each presenter for more detail.

General Concepts for Defining and Measuring Congestion
Presenter: Shawn Turner (Texas Transportation Institute)

Shawn Turner opened the morning session with his presentation on the approaches to defining and measuring congestion and mobility that have been developed by the Texas Transportation Institute. Turner stressed the importance of basing the definitions of congestion on how customers of the highway system "measure" congestion. Highway users relate congestion to the time it will take them to get from point A to point B. In addition, highway users often attach a reliability factor to their assessment of how the road system is performing.

Turner described some important aspects of travel time-based measures of system performance: travel time - based measures are meaningful to both technical and non-technical audiences; allow cross-modal comparisons; are useful for evaluating land use and transportation impacts, and can be related to decisions made by travelers, shippers and agencies.

Key travel time-based measures include travel time index, percentage of congested travel, delay per person and buffer index. A travel time index is obtained as the ratio of travel time during peak congestion to off-peak while a buffer index is a kind of reliability measure, an extra "buffer" time added to average travel time to ensure that one is late only by "X percent" of the time. Below is an example of travel time index for several major cities including Phoenix.



Congestion Mitigation Strategies: National Overview
Presenter: Tim Lomax (Texas Transportation Institute)

Tim Lomax opened his presentation with an overview of the nature and extent of the congestion problem. He aptly described the determinants of congestion that include "long" travel times, "unreliable" travel conditions, "long" waits at signalized intersections, the growth and spread of congestion into local roads and outlying areas, and, customer expectations. The complex nature of the congestion problem calls for a more systematic process that looks at the regional trends and issues, creates a vision, identifies goals and audiences, formulates policies to achieve goals, develops performance measures and objectives, identifies problems and tests solutions (with consideration of cost effectiveness and public support), and develops solutions within the vision.

Lomax then moved on to discussing solutions to the congestion problem. He described the traditional approach of spending money on building roadways in Phoenix and the "spend money and gain consensus" approach used in Houston. Despite tripling the size of freeway system in Phoenix, average delay per driver has increased slowly from 30 hours in 1988 to 35 hours in 1997. On the other hand, travel time in Houston has increased by 4% despite the building of freeways, streets, toll highways and transit. In short, building additional roads does slow the growth of congestion, but building roads alone will not be sufficient.

Lomax stressed the need for a paradigm shift to better deal with the congestion problem. In his words, we need to "do more, do it better, do it smarter, and take a regional approach". Solutions should include roadway, transit and bicycle and walk paths. Moreover, the solution should also include better traffic signals, freeway ramp control, incident management, traveler information (in both urban and rural), transit operations and information, event management, and driver education.

Transit improvements should include vehicle location and schedule information, transit priority where warranted, dynamic routing and improved service speed.

Lomax stressed that incident management is key to a reliable highway system. Components of incident management systems (IMS) should include: locating breakdowns and accidents and removing them quickly; better agency communications and cooperation; creating expectations and publicizing them. Some examples of such deployed IMS are in Chicago, Detroit, Los Angeles, Minneapolis-St. Paul, Seattle and Washington D.C.

The solution should also include smarter institutional arrangements, land use pattern options, urban design treatments and pricing options. Suburban design changes should recognize more diverse markets, provide bike/walk incentives, adjust regulations and standard designs, and bring together jobs, shops and homes. Creative urban solutions must compete with suburbs, reinvest in neighborhoods, parks and schools, rehabilitate/reconstruct/clean existing infrastructure, apartment rent, bank loans and development approval.

The ultimate win-win solution should take account of the following:

- Improved mobility (less time driving and more reliable routes, more options for modes and paths),
- Improved developments (diverse urban designs, control effect of "travel time budget"), and
- Improved thinking (what is possible and the likely effect?, schools, safety, parks, shopping, cost).

Performance-Based Planning
Presenter: George Mazur (Cambridge Systematics)

George Mazur defined his presentation topic in his opening slide subtitle, as "Linking Congestion Monitoring to Planning and Programming." Cambridge Systematics has a history of providing support resources for ADOT's Transportation Planning Division, and their experience was very relevant to the points and conclusions of this presentation to the conference.

The initial points of the presentation dealt with the title's critical "Link" between planning and programming, and the monitoring and measurement of congestion. Mazur then established the relationship between long-range planning, programming, and implementation, in an overview of performance-based planning.

With a detailed flow chart of the performance-based planning concept, he explained the process whereby clear goals and valid performance measures lead to alternative strategies, to be evaluated with appropriate selection criteria. This analytical process, based on sound definitions and valid, relevant data, can produce cost-effective strategies. Some applications for this process include policy analysis, corridor and project-level analysis, resource allocation and programming.

The steps for implementing performance-based planning were covered in detail, in discussion of the earlier flow chart graphic. This process overview was further referenced to NCHRP 446, as a resource for the application of the concept. Mazur went into greater detail in discussing the key steps in the process, from past experience of Cambridge Systematics with a variety of client agencies and process stakeholders. The main areas that he detailed included development of performance measures, data needs, data resources, and data collection methods.

Several real-world examples were discussed including Colorado, Oregon, Florida, and California, among others. A number of regional or corridor congestion programs were also highlighted.

Regional Congestion Monitoring in Phoenix
Presenter: Mark Schlappi (Maricopa Association of Governments)

Following a short break, the Conference focus shifted from the national state-of-the-practice to the Arizona perspective. Mark Schlappi was on hand to represent the Maricopa Association of Governments (MAG), whose area of transportation concern covers the entire sprawling Phoenix metropolitan area.

Schlappi provided a detailed overview of the objectives and methods of past efforts, and more recent regional congestion analyses and planning studies performed or commissioned by MAG. He noted that between 1989 and 1998, the Valley of the Sun region had experienced a 40 percent increase in population. Since 1991, MAG has established and updated electronic databases for regional transportation analysis and planning.

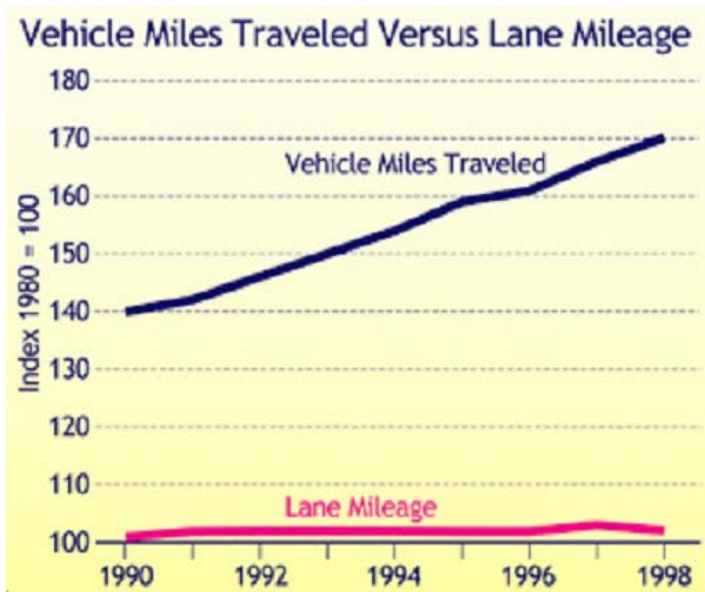
MAG has commissioned a variety of recent studies, by various means, to capture and to deal with this relentless growth. One successful regional survey approach involved Skycomp, performing an aerial photography analysis of Valley freeways in 1998. The study was repeated in 2001, with significantly more centerline miles of coverage. These projects provided density-based level-of-service performance measures. The results of the new re-study are being drafted at this time.

Aerial surveys were one of several data collection methods for the milestone 1998 MAG Regional Congestion Study, which gathered detailed traffic data from the entire Valley, including 10 cities. The study analyzed 669 major intersections as well as 231 directional miles of freeways. The goal was to develop objective measures of relative congestion across the Valley, for the major measurement points and links as described. Schlappi told the group that updates were being programmed, and new GPS-based analyses in 2002 would both build on the current resources and provide new current travel speed data.

Several key MAG resources which were elements of Mark Schlappi's presentation are posted as PowerPoint files on the BWR conference website. They are MAG's Long Range Highway Traffic Forecasts, the MAG 1999 Congestion Study, and the 2002 Study of Travel Speed and Delay in the MAG Region.

Congestion Monitoring and Management in Rural Arizona
Presenter: Rick Powers (Arizona Department of Transport District Office)

Rick Powers provided an overview of the congestion challenges besetting rural areas. Before describing the congestion issues in rural context, Powers described the congestion problem in the general context. He reinforced earlier speakers' description of congestion with statistics indicating the large disparity between vehicle miles traveled and lane mileage provided as shown in the figure. Further, Powers described the reasons behind the congestion as caused by heavy traffic, roadwork, accidents and traffic signals. Of these, heavy traffic is the main cause of delay most often experienced.



Powers then moved on to discussing the current congestion issues in the rural context, which include: older highways with no shoulders, increased speed limits, impatient drivers, lack of passing zones, increased vehicular travel demands, lack of sufficient lanes, mix of cars and trucks, lack of passing lanes and lack of climbing lanes. He emphasized the problem of 2-lane roads typical in rural areas where the mix of cars and trucks and lack of passing and climbing lanes greatly affect the Level of Service.

Suggested solutions to mitigate congestion in rural areas include: widen old highways with adequate paved shoulders, construct additional lanes to accommodate traffic, realign to improve sight distance and increase pass zones, construct additional passing and climbing lanes, provide reversible lanes if possible, construct turn outs, construct short 4-lane segment to relieve flow, special intersection treatments, provide alternate routes to major destination, promote alternate modes of transportation, promote carpooling, shift travel from congested areas, promote public transit, and promote telecommuting.

Other Regional Arizona Perspectives – PAG and Pima County
Co-Presenters: Charles Hodges (Pima Association of Governments)
Albert Letzkus (Pima County)

The congestion mitigation resource project is mandated to develop a balanced perspective and mix of relevant planning resources for all of Arizona, and the project team had to ensure that all areas of the state were fully represented. The planning perspective for the Tucson metropolitan region was provided by both the regional planning association (PAG) and by Pima County.

Albert Letzkus of Pima County spoke first and made a number of key points in regard to the rapid growth throughout the county and its impact on the regional transportation system. He noted that the future emphasis will be on upgrading of arterials to four or six lanes, even in the current rural areas. He also noted that the County's traffic signals at 72 locations are being linked to the City's ICON coordination system.

Letzkus provided several examples of areas or corridors where congestion was evolving most rapidly, and he closed by noting that the "missing link" in the transportation system is new freeways. Unlike Phoenix, no new routes are currently being planned.

Charles Hodges of the Pima Association of Governments then gave an overview of the regional data collection and modeling activities. Baseline regional traffic modeling studies date to 1993, and have been updated in 2000. He noted that tying congestion measurements and modeling to air quality measurements and standards is a growing challenge.

Hodges noted that from PAG's perspective, travel time is a very valuable measurement. As to planning resources, he mentioned that incentives and disincentives are both seen as options. Resources on a regional system-wide basis for the future will include incident management, ITS, and HOV lanes. In conclusion, he said that PAG's planning program will focus on both current and future congestion conditions.

The ADOT Perspective – Planning and Operations
Presenter: Dale Buskirk (Transportation Planning Division)

After a morning of presentations on national, regional and local congestion issues, measures and potential solutions, the final presentation of the session was intended to provide the perspective of ADOT on the congestion question. Dale Buskirk gave the group an overview of the State's goals and of TPD's responsibilities for long-range planning and programming of projects.

The Transportation Planning Division performs its functions within parameters established not only by good practice but by both ADOT policy and state law. Vision 21 has made a number of recommendations that have been included in proposed legislation, HB 2660. If passed, there would be significant changes to the way planning and programming is done.

Vision 21 was established to recommend and prioritize the goals, funding, and specific plans for the State to deal with critical transportation system issues in the new century. The Task Force recommendations most affecting TPD are that ADOT long range plans must identify performance outcomes anticipated from projects, and that performance-based processes are required for all projects and priorities in these plans. Vision 21 also called for statewide standards for these processes to be applied by the Transportation Board in future project funding at all levels. However, HB 2660 mandates that only ADOT (TPD) is required to implement a performance based process.

The State Transportation Plan is to be developed under these mandates by TPD using a three phase approach. The first phase of the process is to conduct a multimodal transportation system analysis. It includes a study of the forces affecting the state's development and an inventory of transportation resources, and it will define the strategic direction for the plan. The second task will be the public involvement phase, and the third phase will develop performance measures and an appropriate evaluation methodology. A performance-based plan will be the end result.

The second part of Dale Buskirk's presentation highlighted the TPD data collection and analysis program, that is now GIS map-based. He presented a series of graphics of the functional classes of the State's transportation system, from Interstates to urban and minor rural collectors. This GIS data supports a series of Level of Service slides, both for the state as a whole and for such cities as Phoenix, Tucson, Flagstaff and Yuma. Buskirk noted that these resources support ADOT planning efforts statewide, for rural corridors as well as all levels of urban areas.

C. Summary of Workshop Discussions

The two afternoon workshops were dedicated to group discussions on the following five congestion related topics. Each topic was assigned to a workgroup with approximately ten participants. Each workgroup had a facilitator and a note taker. At the end of each workshop discussion, the note takers provided a summary of the deliberations.

1. Definitions of Congestion
2. Congestion Mitigation Strategies (supply and demand sides)
3. Techniques for Evaluating and Comparing Congestion Mitigation Strategies
4. Rural congestion
5. Institutional Issues and Policies

Following is a summary of the roundtable discussions on the above congestion topics.

Workgroup 1: Institutional Issues
Facilitator: Bob Mickelson (Transportation Consultant)

The current mode of operations of public agencies does not necessarily promote open discussion and cooperation on the issue of congestion mitigation. While it is logical to expect that all affected jurisdictions should be involved in decision making, the often conflicting agency goals may impair cooperation. The long range planning process can be used as a common platform for open communications between agencies where new ideas can be brainstormed and evaluated. Larger agencies, like ADOT, should work with local jurisdictions to implement selected mitigation strategies. These and other ideas, summarized below, were discussed at Workgroup No. 1.

Key Points

- Congestion issues can be viewed as general operations and planning issues.
- There is a need to incorporate local planning issues into congestion mitigation planning.
- ITS is a sensitive issue.
- Parochialism is a major concern. Agencies have conflicting missions, values, goals and objectives. Agencies, such as ADOT, MCDOT, MAG and RPTA have institutional cultures that tend to think only from their particular perspective. Many of these institutional predispositions lie with agency staffs. There is a need to break down barriers, to think and work jointly, and to make joint use facilities. Common ground needs to be found among communities, agencies and businesses.
- Congestion needs to be looked at from a collective institutional viewpoint. All affected jurisdictions should be involved in making the decisions.
- Long range planning offers the opportunity for cross communication and pollination of ideas. Long range regional and statewide plans should provide overall direction. Owner agencies like ADOT should use this direction and work with affected local agencies to decide and implement specific congestion mitigation strategies.
- Outside the metropolitan areas, there is a need to work with statewide agencies such as DPS and AAA. There may be conflicts between local, such as small community development goals, and regional and system travel needs.
- If a congestion mitigation strategy affects someone, then they need to be involved in the decision-making process.
- Turf issues must be considered. For example, inter-regional travel between MAG and PAG is becoming an issue with those regional agencies. As a result they are beginning to discuss this issue. That could lead to turf issues with CAAG that is sandwiched between them.
- HOV lanes and congestion pricing are examples of cross-jurisdictional issues that require the involvement of multiple jurisdictions.
- The appropriate lead agency for selecting congestion mitigation strategies depends on the strategy. ADOT might be the lead agency for making ITS decisions on the State Highway System. On the other hand, parking supply or rates are appropriately a local decision, although ADOT could suggest that they be considered.
- The determination of performance standards should be a cooperative process. There should be regional discussion with local input. Performance criteria need to be understandable to all affected agencies and the public.

- Project development is more of a local/sub-regional process under the umbrella of regional or statewide planning guidance.
- Congestion mitigation discussions should be divided into consumer value-based (outcome) and professional/technical-based (output).
- Care must be taken to consider the implications of state imposed values and priorities on regional and local values and priorities.
- Statewide decisions should be needs based as opposed to equity based.
- Demand side mitigation strategies should be considered even though they may be more institutionally sensitive.
- Other statewide and federal agencies, such as DEQ, State Lands, Forest Service and Indian Tribes need to be involved in congestion mitigation strategies that affect their interests.
- Business decisions and practices have a huge impact on congestion. Private/public or public/private congestion mitigation partnerships need to be considered. Carpool/vanpool, staggered work hours and remote work site programs are examples. The private sector has a lot of data that would be of value in making congestion mitigation decisions.
- Intercity transportation carriers should be part of the decision making process.
- Elected officials need to be involved in congestion mitigation discussions about strategies on which they will eventually be required to decide.
- Approaches that could help overcome the institutional cultural problem include staff exchange programs and frequent regularly scheduled meetings or interactions among agencies with common interests (but different viewpoints).
- ADOT needs to have its telephone directory, and possibly email addresses, on line.
- Small community and Tribal cultures need to be considered in congestion mitigation decisions.
- The loss of rural employment, requiring long commutes to urban centers is a factor in congestion.
- There are a lot of gaps out there, such as generational gap thinking and territorial gaps involving differing community values. A lot of private sector institutions are not public institution friendly. These gaps need to be bridged to successfully implement some mitigation strategies.
- There is a need to have the ability to access and understand institutional data that affects congestion mitigation strategies.
- Congestion means different things to different people both inside and outside organizations, again pointing to the need to find common ground and understanding.
- ADOT has a role in congestion education and facilitating, not dictating, congestion solutions.
- Congestion is a local mind-set and needs to be understood from the local perspective.
- There is no need to create another institution to address congestion.
- The private sector should be held accountable for new congestion and transportation system demands that they create through new or expanded development.

Workgroup 2: Congestion Mitigation Strategies
Facilitator: Nayan Amin (Bucher, Willis & Ratliff Corporation)

Various mitigation strategies for congestion were mentioned. These were grouped into categories including: Travel Demand Management (TDM), Transportation Systems Management (TSM), TSM Rural, Transit, Operations and others. The strategies cited for each category, together with some associated issues are summarized below.

Key Points

- TDM strategies include parking, employer-based programs, flexible work hours, guaranteed ride home program, Park-N-Ride, telecommuting, mode shift, market-based approach and land use planning.
- There was some understanding that increasing the supply of parking is not reasonable in the long run. It was suggested to place limits on development expansion in Tucson but not in Phoenix. There was recognition of the position of business community that should be considered in any parking strategy.
- Offering discounts of 50 to 100% for transit passes could be looked at. PAG orchestrated programs with municipalities to solicit participation by businesses; this strategy may have some potential. It was recognized that good services and incentives need to be provided for employer-based programs to succeed.
- In a similar vein, the following factors were cited as vital for other programs to be effective: provide incentives to shift mode, safe Park-N-Ride facilities, better transit information schedules, phones and internet access. Also, improve coordination/continuity for bike/pedestrian systems.
- For market-based approach, tolling such as pricing of an HOV lane was suggested. This may involve privatization or private/public partnerships.
- Consideration of urban renewal and growth management was suggested for strategies involving land use planning.
- It was pointed out that a compressed work program could have potential in Arizona.
- TSM related strategies include: lane capacity addition/improvement, merge/diverge lanes, HOV bypass, freeway to freeway connections, ramp metering, reversible lanes, construction management, intersection improvements and collectors/distributors.

- For lane capacity addition/improvement, participants identified SOV and HOV on freeways, downtown bus lanes, Bus Rapid Transit (BRT) using HOV lanes on freeway, 24-hour HOV versus legislation.
- Under construction management, these strategies were cited: phasing/scheduling of regional construction, acceleration of construction, A+B bidding, lane rental concept, better traffic control and lower rental rates during night work.
- For intersection improvements, right turn lanes, dual lefts, roundabouts and bus pull outs were identified.
- Participants also identified the need for improving frontage roads.
- TSM rural strategies include: providing passing and climbing lanes, increasing shoulder width, improving road alignment, intersection treatments including grade separation, widening to 4 lanes, imposing restrictions on trucks, providing alternate routes such as by pass in town centers and access control.
- Transit related congestion mitigation strategies include: priority for transit services, providing bus pullouts (including freeway locations), equipping buses with Automatic Vehicle Location (AVL) systems, yield signs on buses, plan for an expanded provision of basic bus routes, obtain a right of way for BRT, build Light Rail Transit (LRT) system, develop a well coordinated intermodal connections, and transit enhancements need to be backed up with land use plans that support viability of transit modes.
- Some measures that can improve the operation and utilization of Arizona's highway system include: signal synchronization/coordination, improved planning of signal spacing to match the urban form, smart corridor (joint management effort, use of cameras for detection), Advanced Transport Management Systems (ATMS), traveler information (internet, links to/from local-state, private partners to disseminate), incident management (work team, freeway service patrol, 511 system, reaction team, quick clearance law, video/filming/GPS to expedite investigation), Variable Message Signs (VMS) before and after directional splits, event management, performance data linked to programming, interagency cooperation/coordination, access management, snow and ice removal (chemical versus cinders), and mitigation strategies for flooding.
- A point was made for significant capacity addition, e.g., double decking or building subways.
- Land use planning, in particular to achieve a sub-regional balance, was emphasized.
- There is a need to examine/develop an effective signal strategy.
- HOV lane management may be needed.
- Feasibility screening is needed by financial and political authority involved.
- Strategies must be realistic.
- There is need for incident management in rural areas.
- Lastly, a question was raised as to which objective should be pursued, whether congestion reduction or congestion management. This raised the question whether the aim is to ultimately reduce demand for car travel in order to reduce congestion or simply to manage the existing demand.

Workgroup 3: Evaluating Congestion Mitigation Strategies
Facilitator: Craig Roberts (Northern Arizona University)

It was acknowledged that congestion is a big and complex problem. Congestion mitigation often requires simultaneous application of multiple strategies at different levels of the transportation system. Current political environment and available funding may effectively set limits on which measures can be used. Other factors and issues discussed with respect to evaluating congestion mitigation strategies were:

Key Points

- Cost should be evaluated as a measure per reduction unit (i.e., travel times, delay per person). Also, total cost must be looked at.
- In practice, evaluation usually adopts the quantifiable measures of money and time (i.e., the monetary value placed on travel time). It was recognized that evaluation must not only consider travelers' valuation of time, but also the value placed on the purpose of a trip and the effects of trip chaining. Moreover, it was recognized that measures need to include environmental aspects and quality of life. For example, set congestion in the context of community value. Likewise, measures should consider the consequences of strategies/investments on economics and quality of life. Thus, ultimately evaluation is a value judgment.
- When evaluating a congestion mitigation strategy, workgroup participants placed emphasis on the following points: a strategy must have a clear goal (e.g., acceptable LOS to be determined); it should be implementable politically; it is imperative to identify at the outset who controls the strategy; the timeframe in comparing strategies ought to be given consideration; and consideration should also be given whether to categorize strategies, or group them one at a time.
- Separately evaluate short fixes and long term solutions.
- Evaluation should find a common denominator when evaluating different modes of transportation that have different characteristics. Moreover, the evaluation should assign weight to those modes that are under-represented.
- Public role in evaluating congestion mitigation strategies was discussed at length. Participants emphasized the need to define public role in the evaluation considering that

public involvement is an iterative process. It was recognized that many transportation users are not vocal, and therefore care must be given to obtain representative opinions.

- The measures of congestion were also covered in the discussions. Travel time versus average speed "as a measure" was suggested. Motorists consider travel time an important factor and it is clear that other qualities cold be measured as well; e.g., extent and duration of travel delays. It was also cited that congestion parameters, such as delay, are not the same at all locations. Some remarked that the measure of congestion is subjective because congestion is based on one's experience.
- Planning measures were considered important in addressing congestion, but land use policies are not controlled by the state DOT. It was suggested, however, that ADOT can play a big role in helping to mitigate congestion through early involvement in land use planning.

Workgroup 4: Definitions and Measures of Congestion
Facilitator: Shawn Turner (Texas Transportation Institute)

Mitigating congestion on a statewide basis will likely benefit from classifying congestion by broad geographic categories, such as the four location types (metropolitan, urban, rural and activity center) described in the Pre-Conference White Paper, as well as facility types and other spatial and temporal attributes. It is clear that popular definitions of congestion require clarification, particularly where the public's perceptions are involved. The notion of acceptable vs. un-acceptable congestion must play a role in this study. While the traditional congestion measures (LOS, travel delay) have obvious value, new - both broader and more refined - definitions need to be embraced to begin addressing the entire spectrum of the congestion mitigation issue. Table 4 benefited from a dynamic discussion on these and other congestion definition related sub-topics, listed below.

Key Points

- The four location types described in the Pre-Conference White Paper do appear to have value. However, they need to be more clearly defined and delineated (e.g., metropolitan vs. urban). In the activity center location type, there may be a need to differentiate between commercial vehicle traffic at the border and recreational traffic. Both groups clearly agreed that expectations would differ by location and facility type.
- In addition to the location types, there may be a need to also distinguish by facility types (access-controlled highway, major arterials, minor arterials, etc.) and characteristics

(availability of alternate routes, probability of incidents/breakdown, strategic importance, etc.).

- Both groups were in unanimous agreement that there was a need to separate the definitions of congestion from the judgments about what is acceptable and what is not acceptable. This seems to imply a definition similar in nature to NCHRP 398's "congestion" and "unacceptable congestion".
- In terms of measures, the first group was split somewhat on whether travel time-based or LOS measures were better. The second group cautioned against using LOS and v/c ratio measures and thought the focus should be on travel time measures. In both groups, there was some feeling that travel time may not fully address or capture the issues/needs outside metropolitan areas. The second group mentioned the need to capture duration of congestion in the measure(s).
- Both groups clearly indicated a need for reliability measure(s) that captured the effects of incidents, weather, and other events. There was no consensus on which reliability measure is best suited for this purpose.
- The second group felt strongly that there is a need to consider the audience (includes both technical and non-technical) in developing the congestion definitions and measures.
- The second group mentioned mobility as a concept that should be considered (as opposed to congestion). They thought mobility was the term more applicable to rural areas. Mobility implies/includes efficiency and comfort of travel. They also mentioned that congestion seemed to be more facility-oriented, mobility was user-oriented.
- The first group suggested traffic density and traffic mix measures in addition to LOS and travel time measures. They thought these measures might be appropriate in rural areas. The second group mentioned safety and passing opportunities as potential additional measures in rural areas.
- Route lengths used in data collection and analyses are critical. Delays can get smoothed out if sections are really long.

Workgroup 5: Rural Congestion
Facilitator: Sharon Hansen (PBS&J)

Rural congestion is an integral part of this project and was given a great deal of attention during the workshops. Two main issues were tackled with respect to congestion in rural areas: definition of rural congestion and solutions to rural congestion. Some performance-based solutions were separately identified.

Key Points

- There was unanimous agreement in both groups that rural congestion is different from urban congestion. Therefore, there is a need to make a clear distinction between these two contexts.
- The two groups were in agreement that there is no single definition that can be attributed to congestion in rural areas. Various factors that affect the level of service in rural roads were identified. Factors that contribute to deterioration of the quality of service in rural roads include: outdated design of road geometrics, recurring rural congestion caused by accidents, traffic mix (the high % of trucks and RV's), effects of weather and other environmental conditions, lack of timely and advance notice of rural bottlenecks, lack of reliable data collection to measure and monitor congestion.
- Lack of alternative routes is an important factor in rural congestion in Arizona, as well as lack of local transit alternatives and amenities including lack of bus pullouts in areas where bus services are available (these include school buses).
- Other issues raised were safety and traffic variation. Safety is a BIG issue in rural context. Rural roads have a large proportion of road fatalities. Moreover, rural traffic is highly seasonal and congestion is likely to occur on weekends and during holiday seasons.
- Participants also cited some behavioral aspects of rural drivers. Expectations among rural drivers could be different. Likewise, habits among rural drivers can be very different than those of out of town drivers (through traffic). Socioeconomic factors may also affect drivers' attitudes. These behavioral aspects need to be considered when defining congestion in rural context.
- Participants cited various TSM related solutions. Some of these were also identified in Workgroup 2 discussions. The measures cited included: updating of road geometrics such as minor grade adjustments, providing alternate routes, integrating bridge crossings with highways, providing passing zone (it was pointed out that the current passing zone policy may be overly conservative) and climbing lanes, improving signal timing, providing pullouts for school buses, raising the speed limit, maintaining acceptable travel time within construction zone, reducing the length where construction speed limit applies, pre-treatment before snow event and access management.
- Technology related measures were also mentioned. These include providing better incident management to clear traffic buildup, adopting different equipment in rural areas for effective incident management, Road Weather Information Systems (RWIS), Highway Closure and Restrictions Systems (HCRS), Variable Message Signs (VMS), Highway Advisory Radio (HAR), and access to the Internet, for example, www.azfms.com.
- It was suggested to establish rural district Operations Centers that could serve as focal points for incident management. This should be attended by at least two staff, one to deal with coordination.
- Another suggestion was to develop partnerships with local enforcement agencies and emergency management personnel.
- Public outreach programs were also mentioned as important in effectively addressing the rural congestion problem.
- Workshop participants also identified the following as performance-based solutions to mitigating traffic congestion (some of these overlap with the solutions mentioned earlier): funding, expanding and better use of ITS alternatives, better planning for growth related congestion, more uniform and consistent signing and striping on roadways, more rural transit service and other alternate modes, more outreach and education programs aimed at legislators, administrators and the public.

- Congestion measurements for rural context should be based on driver expectations and not just on classical or traditional level of service measurements.
- There is a need to educate drivers to better handle rural conditions.

D. Key Outcomes and Next Steps

The input gathered through the March 5 conference and workshop will be valuable to the remaining study analysis and the research recommendations. Several major tasks remain to be completed before a draft set of recommended congestion strategies will be presented to ADOT:

- Conduct Industry Survey (in progress)
- Develop a List of Congestion Remedies for Arizona (in progress)
- Analyze Impacts of Congestion Mitigation Strategies (in progress)
- Summarize Advantages and Disadvantages of Alternative Strategies (in progress)
- Identify High-Level Indicators of Relative Costs and Benefits of Alternative Strategies Based on Proposed Performance Measures.

The final key project tasks are:

- Prepare Draft Recommended Strategies Report
- Deliver Presentation to the Core Team and the TAC
- Finalize Congestion Mitigation Strategies Report
- Prepare Final Research Report and Research Note