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16. Abstract

Texas cities are currently considering the managed lane concept for major freeway projects. As a new concept of operating freeways in a flexible and possibly dynamic manner, the managed lane concept has a limited experience base, thereby creating a knowledge vacuum in emerging key areas that are critical for effective implementation. Complicating the effort is the rapid progress of several freeway improvement projects in Texas in which TxDOT is proposing managed lane operations. The operational experience both in Texas and nationally for managed lanes is minimal, particularly for extensive freeway reconstruction projects. The managed lane projects currently in existence involve retrofits of existing freeway sections within highly fixed access, geometric, and operational configurations, and established eligibility considerations. There are few projects in operation from which to draw experiential data on the implementation of managed lane freeway sections with complex or multiple operational strategies, including variations in eligible vehicle user groups by time of day. The objectives of this project are to investigate the complex and interrelated issues surrounding the safe and efficient operation of managed lanes using various operating strategies and to develop a managed lanes manual to help the Texas Department of Transportation (TxDOT) make informed planning, design, and operational decisions when considering these facilities for its jurisdiction. This document presents the critical research results obtained over the five years of this project.

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FINDINGS FROM TEXAS: FIVE YEARS OF RESEARCH ON MANAGED LANES

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The engineers in charge of the overall project were Beverly T. Kuhn (Texas P.E. #80308) and Ginger Daniels Goodin (Texas P.E. #64560).

The United States government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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- Alvin Luedecke, Jr., P.E., Transportation Planning and Programming Division, TxDOT (Retired)
- Jay Nelson, P.E., Dallas District, TxDOT (Retired)
- Steven E. Simmons, P.E., Deputy Executive Director, TxDOT
- Robert Wilson, P.E., Design Division, TxDOT (Retired)

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CHAPTER 1: INTRODUCTION

BACKGROUND

The increasing population growth in Texas places enormous demands on the transportation infrastructure, particularly the freeway systems. There is a growing realization that the construction of sufficient freeway lane capacity to provide free-flow conditions during peak travel periods cannot be accomplished in developed urban areas due to:

- cost,
- land consumption,
- neighborhood impacts,
- environmental concerns, and
- other factors.

Like other transportation agencies nationwide, the Texas Department of Transportation (TxDOT) is searching for methods to better manage traffic flow and thus improve the efficiency of existing and proposed networks.

A viable method for meeting mobility needs is the concept of "managed" lanes, which is growing in popularity among users and agencies alike. Managed lanes maintain free-flow travel speeds on designated lanes or facilities by providing controlled service to eligible groups of vehicles. Moreover, the eligible user groups can vary by time of day or other factors depending on available capacity and the mobility needs of the community. Because true managed lanes are so new and the experience base is so small, numerous issues surrounding their design and operation deserve additional exploration as planning for them progresses.

Managed lanes are similar to special-purpose lanes, which have been evolving for several decades. Initially, freeway lanes employed access restrictions to control the amount and entry location of traffic, thereby assuring smoother flow and maximum efficiency. Later, the development of high-occupancy vehicle (HOV) lanes increased total person movement by providing a lane or lanes designated for buses, vanpools, and carpools only. In the last few years, several HOV lanes have begun using electronic tolling to expand the eligible groups of users, thereby further improving on operating efficiency; those facilities are generally referred to as "HOT" (high-occupancy toll) lanes. Recently, transportation agencies have become more interested in not only controlling eligibility, but also in retaining real-time control over portions of a roadway via variable mechanisms such as price and/or eligibility.

With the exception of pure HOV lanes, the knowledge base for all forms of managed lanes projects is very limited. In addition to the Katy (IH-10) and Northwest (US 290) QuickRide projects, other similar projects also operate in the United States, including:

- IH-15 FasTrak project in San Diego;
- SR 91 Express Lanes project in Orange County, California; and
- IH-394 MnPASS Express Lanes in Minneapolis, Minnesota.

These projects have extensive evaluation programs that examine effectiveness of the projects against established goals and objectives. Agencies and researchers can learn much from these experiences. However, all of these projects involve retrofitting existing freeway operations within fixed access, geometric, and operational configurations. Virtually no projects in operation offer researchers and transportation agency staff experiential data on the implementation of managed lane freeway sections with multiple operational strategies, including variations in eligible vehicle user groups by time of day.

TxDOT anticipates the managed lanes operational approach will offer peak-period free-flow travel to certain user groups. These user groups might be:

- HOVs,
- trucks,
- toll-paying vehicles,
- transit,
- low-emission vehicles, or
- some combination of these and other groups.

The current HOT lane pilot projects on the Katy (IH-10) and Northwest (US 290) freeways in Houston are working examples of the potential application of allowing more than one vehicle user group into a lane designated exclusively for their use during peak travel times.

At present, several major investment studies (MIS) are under way or completed in Texas that consider some form of managed lanes within upgraded urban freeway sections. In several of these cases, regional transportation agencies have made a public policy decision to proceed with multiple managed lanes within a general purpose lane operating environment. Researchers must now address the traffic engineering issues of geometric design and functional operation to make these projects a reality. However, as stated previously, researchers know little about the complexities of designing a practical, flexible, safe, and efficient facility that may have multiple operating strategies throughout the course of a day, week, year, or beyond. Thus, TxDOT initiated this project to research these and other issues that need answering to help ensure the successful implementation of managed lanes.

PROJECT VISION AND OBJECTIVE

TxDOT's needs associated with managed lanes research are broad and diverse. Answering any and every question associated with the planning, design, and operation of managed lanes in every conceivable scenario within the framework of one single project is difficult. Thus, in an attempt to clarify the overall direction of this project and to identify those issues the researchers plan to resolve, the project team drafted a vision and objective for the project. The idea was to ensure that all involved with the project were in agreement as to where the project was going and clarify the expected outcome for the final product that will facilitate the implementation of research results.

The research supervisors, in collaboration with the Texas Transportation Institute (TTI) Advisory Committee, identified the *vision* of managed lanes research as it related to TxDOT. This vision was to develop a better understanding of how managed lanes can improve mobility for transportation system users. The *objective* of this managed lanes project was to investigate the complex and interrelated issues surrounding the safe and efficient operation of managed lanes and to develop a managed lanes handbook to help TxDOT make informed planning, design, and operational decisions when considering these facilities for their jurisdiction.

Although the vision and objective of the project were conceptual, the research team realized that the key staff within TxDOT who will actually implement the research results need to understand what the project will provide to enable them to accomplish their jobs when involved in a managed lanes project. Thus, the research team identified typical questions that the project intended to answer. These questions, as provided in Table 1-1, represent a comprehensive, though not exhaustive, look at the intended results of the project.

PROJECT MANAGEMENT STRATEGY

The complex nature of this project required a well-defined and coordinated project management strategy. The project management team structure outlined in Figure 1-1 provided for TxDOT oversight and guidance from the program coordinator, project director (PD), and project monitoring committee (PMC). It also provided for input from key stakeholders to ensure their buy-in on managed lanes projects in their region via the external stakeholder committee. Beverly Kuhn, head of the System Management Division at TTI, and Ginger Goodin, head of the Austin Office of TTI, led the research team. Ad hoc technical advisory committees supported specific tasks within the research effort and had TxDOT staff and other stakeholders as members, as appropriate. Researchers from TTI and Texas Southern University (TSU) who possess expertise in specific areas of interest led the various project tasks with guidance from the research supervisors and task-related technical advisory committees.

Table 1-1. Questions to Be Answered by Project 0-4160 Research.

Managed Lanes Project Phase	Critical Questions to Be Answered
Planning Managed Lanes Facilities	What are the operational options available for a managed lanes facility? How does an intended user group(s) affect a managed lanes facility's design and operations? What defines a successful managed lanes project? How can I fund and finance a managed lanes project? How do I market a managed lanes project to help make it a success? How do I integrate other key agencies (transit, toll, law enforcement, etc.) into a managed lanes project to help overcome institutional issues and barriers? Are there any interim or temporary uses for a managed lanes facility?
Designing Managed Lanes Facilities	How do I design a managed lanes facility to handle a selected user group? How can I design a managed lanes facility to be flexible for future needs? What safety issues do I need to be aware of when designing a managed lanes facility? What interoperability issues do I need to be aware of when designing a managed lanes facility? What information do users need to make decisions about using a managed lanes facility? What approaches to delivering user information can be used to provide that information appropriately?
Operating Managed Lanes Facilities	What is the best way to enforce a managed lanes facility? How do I handle incidents on a managed lanes facility? What staff do I need to manage a managed lanes facility, and what training do they need? How do I evaluate and monitor a managed lanes facility to determine success?

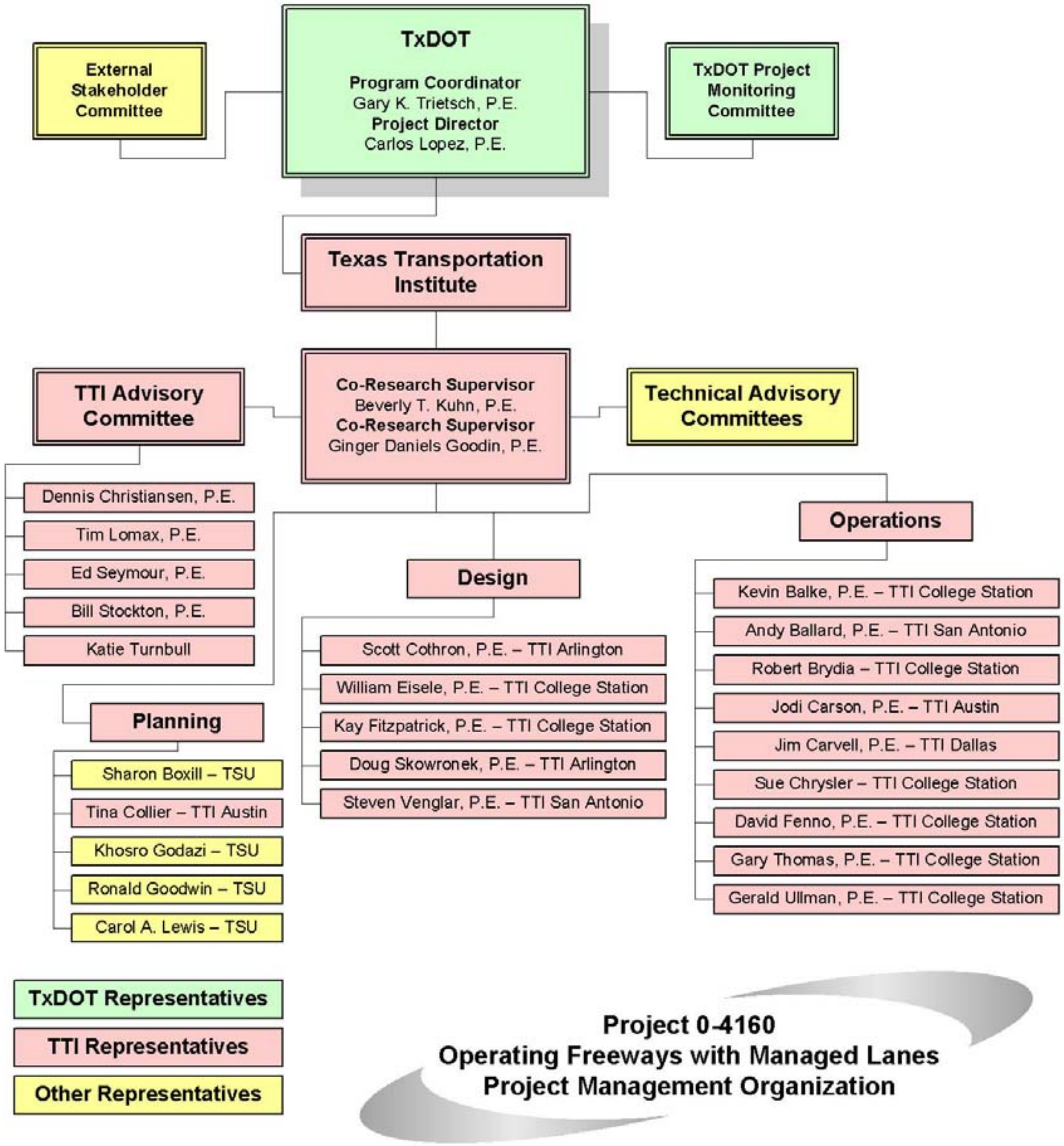

Figure 1-1. Project Management Organization.

TxDOT Project Monitoring Committee

The project monitoring committee, composed of seven district engineers and seven engineers from various TxDOT divisions, assisted the project director, the program coordinator, and the project team in directing the project to meet the needs of TxDOT. The PMC participated in the annual TxDOT workshop, provided input regarding the work plan and critical research needs, and ensured that the overall objectives of the project were met.

External Stakeholder Committee

The external stakeholder committee had members from various key agencies and organizations in Texas, including:

- cities,
- metropolitan planning organizations,
- transit and toll authorities,
- motor carriers, and
- others.

Meeting once a year, this committee worked with the project team to see that researchers considered the stakeholder interests and concerns throughout the project. The intent was to ensure the future buy-in of these stakeholders to managed lanes projects in the state.

Texas Transportation Institute Advisory Committee

TTI provided the project team with an advisory committee composed of key leaders and TTI researchers at no cost to the project. These committee members have international reputations as leaders in the technical areas required for a successful research project. The project team met with this committee periodically to discuss:

- the direction of the project,
- specific tasks,
- problems encountered,
- results and findings, and
- other issues critical to the success of the project.

This strategy allowed the committee’s direct involvement in the project in the most efficient and effective manner possible. The committee’s involvement helped to ensure that no aspect of the operation of managed lanes was overlooked and the best possible results were reached.

Technical Advisory Committees

TxDOT staff from various districts and divisions as well as other related stakeholder organizations participated in ad hoc technical advisory committees throughout the course of the project. Researchers assembled these committees on a task basis, and the task leaders charged the members with providing technical insight and guidance to the project team for that task. This strategy ensured that the research team met the particular needs of the districts, divisions, and organizations in a manner that worked with the TxDOT process while meeting the objectives of managed lanes.

CHAPTER 2: GENERAL ACTIVITIES

The research team worked on a number of activities directly related to the overall success of the project and implementation of research results. The following sections highlight these activities and the specific accomplishments or developments in each.

INTERNET SITE

A key component of research success is implementation. However, ensuring that practicing transportation professionals have access to research results is challenging. Thus, to help facilitate implementation, the research team and TTI advisory committee developed a project website to provide an avenue for disseminating research results and exposure to the research surrounding managed lanes. The Managed Lanes site, which has an Internet address of http://managed-lanes.tamu.edu:

- highlights the research that TTI conducted for TxDOT on managed lanes on this project,
- provides key research results and access to related products,
- provides information on meetings and other events related to managed lanes across the country, and
- features links to key related Internet sites.

Readers can also access the quarterly newsletter, *FastLane*, online and join the mailing list. Figure 2-1 is a snapshot of the website's home page. The research team intends to maintain this site in some form after the completion of the research project.

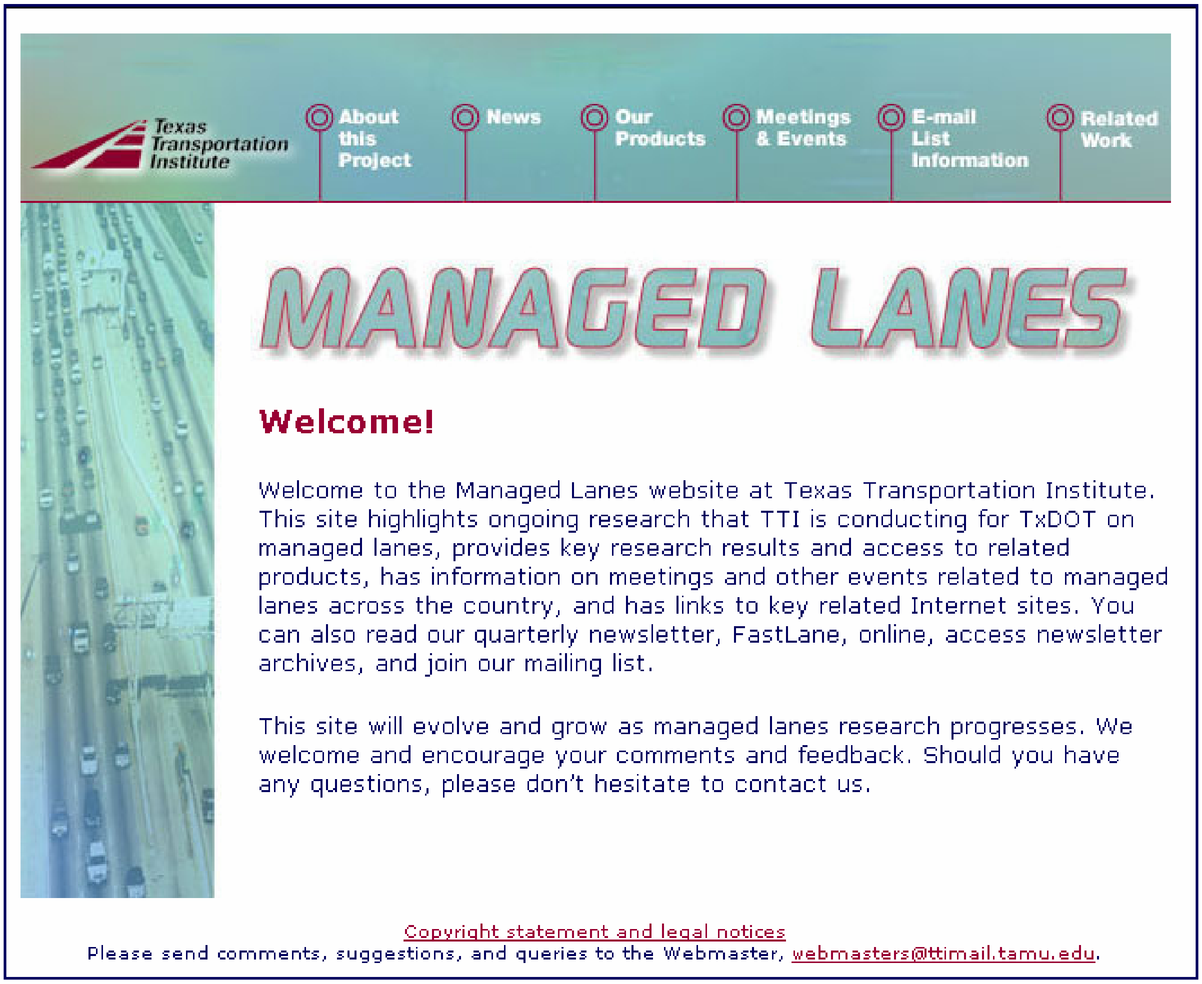

Figure 2-1. Managed Lanes Website.

QUARTERLY NEWSLETTER

To assist implementation, the project team published a quarterly newsletter to document lessons learned throughout the duration of the project. This newsletter, *FastLane*, allowed department engineers and other key personnel quick access to implementable research findings without having to wait until completion of the project. The team published the newsletter electronically, with the approval of the project director, and distributed it to the project mailing list of over 400 transportation professionals. The researchers reached an even broader audience by posting the newsletter on the project website. Figure 2-2 illustrates the format of the newsletter. Over the course of the project, the research team published 12 newsletters with positive feedback from readers.

Managed Lanes – Increasing Highway Efficiency

FAST LANE

Spring 2005

Welcome to FastLane

This is the twelfth issue of *FastLane*: a quarterly newsletter that highlights ongoing activities and research in managed lanes in Texas. Previous issues can be found in the *FastLane* archives on our web site, http://managed-lanes.tamu.edu. Please feel free to forward this newsletter to anyone who might be interested in its contents, and as always, we welcome your comments and suggestions.

Managed Lanes in the News

Turning Lanes into Labs

A February 14, 2005, article in the *Dallas Business Journal* examines a managed lanes research study on I-30 in Dallas that studied driver attitudes and behavior. The managed lane facility, scheduled to be completed in 2007, will consist of lanes that will be used as either high occupancy vehicle (HOV) lanes or toll lanes. The full article can be accessed at http://dallas.bizjournals.com/dallas/stories/2005/02/14/focus1.html. Related stories regarding the I-30 managed lanes project were found in the November 10, 2004 issue of the *Fort Worth Star Telegram* titled "I-30 Gets Go-Ahead for Special Toll Lanes" and "Toll Lanes May Help Traffic to Stadium." These articles by Gordon Dickson describe the project and its goals as well as the possible effect the lanes may have on traffic bound for the proposed Dallas Cowboys stadium and the Arlington entertainment District.

HOV Privileges and Hybrids

Several articles related to the privilege of allowing single occupant hybrid cars to use HOV lanes appeared recently in a number of newspapers and journals. A number of states have laws related to the use of HOV lanes by hybrid vehicles, but these laws can not be implemented until approved by Congress. Currently only Virginia has laws governing hybrid vehicles in HOV lanes.

Virginia has encountered a surge of hybrid vehicles using HOV lanes in recent years. Surveys and traffic counts revealed that in the spring of 2004 8 percent of cars using HOV lanes were single occupant hybrid cars. By October 2004 that number had increased to 18 percent. As a result, a task force comprised of the Virginia Department of Transportation (VDOT) and the Virginia State Police Department recommended that the exemption allowing hybrid single occupant vehicles to use HOV lanes be allowed to expire in July 2006. A copy of the task force report can be accessed on the VDOT web site www.virginiadot.org. Full text articles regarding this issue are "As Hybrid Cars Multiply, So Do Carpooling Gripes" by Steven Ginsberg and Carol Morello, *Washington Post* January 7, 2005 issue; "Significant Increase in Hybrid Vehicles Strains HOV Lanes in Northern Virginia" found in *The Urban Transportation Monitor* January 21, 2005 issue, and "HOV Privilege Elusive for Owners of Hybrid Vehicles" by Lisa Mascaro, *Los Angeles Daily News* January 26, 2005 issue.

Figure 2-2. *FastLane*, Managed Lanes Quarterly Newsletter.

CONTACT WITH PROJECT REPRESENTATIVES

The project team periodically contacted TxDOT staff who are instrumental in the various managed lanes projects across the state. Throughout the length of this project, the research team met with representatives from the Austin, Dallas, Fort Worth, Houston, San Antonio, and Waco TxDOT districts to discuss project progress and key findings relevant to their specific projects.

REPORTS, PRODUCTS, PRESENTATIONS, ABSTRACTS, TECHNICAL PAPERS, AND OTHER EFFORTS

Researchers also helped disseminate research results through presentations, abstracts, and technical papers. Whether at the local, state, national, or international level, these tools served as powerful allies in giving practitioners access to the latest information to help them in their respective organizations. Over the course of the project, researchers made presentations to and/or prepared technical papers for numerous conferences, meetings, and organizations, as highlighted in Table 2-1. Additionally, the research team provided monthly status reports to the project director and program coordinator, and prepared additional products and items that assisted with the research effort and disseminating research results. Table 2-1 summarizes all of these items as well as the project's official deliverables.

Table 2-1. Published Project Deliverables and Products.

Type of Product	Description/Title/Event
	Fiscal Year 2005
Reports	Task 16 Report: Incident Management (FHWA/TX-05/0-4160-17) *Incident Management for Managed Lanes*
	Task 17 Report: Interoperability (FHWA/TX-05/0-4160-18) *Interoperability Issues on Managed Lanes Facilities*
	Annual Research Report: Year 4 (FHWA/TX-05/0-4160-19) *Year 4 Annual Report of Progress: Operating Freeways with Managed Lanes*
	Task 19 Report: Staffing and Training Needs (FHWA/TX-06/0-4160-20) *Staffing and Training Needs for Managed Lanes Facilities*
	Task 6 Report: Decision Matrix (FHWA/TX-05/0-4160-21) *Decision Framework for Selection of Managed Lanes Strategies*
	Task 20 Report: Strategies for Interim Use (FHWA/TX-05/0-4160-22) *Strategies for Interim Use of Managed Lanes*
	Task 21 Report: Evalution and Monitoring (FHWA/TX-06/0-4160-23) *Monitoring and Evaluating Managed Lane Facility Performance*
	Task 23 Report: Managed Lanes Handbook (FHWA/TX-06/0-4160-24) *Managed Lanes Handbook*
	Project Research Report (FHWA/TX-06/0-4160-25) *Findings from Texas: Five Years of Research on Managed Lanes*
	Project Summary Report (FHWA/TX-06/0-4160-S) *Findings from Texas: Five Years of Research on Managed Lanes*
	Proceedings of Annual Workshops for TxDOT (not published) *Meeting Summary: 2004 Annual Project Monitoring Committee Workshop*

Table 2-1. Published Project Deliverables and Products (continued).

Type of Product	Description/Title/Event
Fiscal Year 2005 (continued)	
Bulletins	*Incident Management for Managed Lanes* (4160-17B)
	Interoperability Issues on Managed Lane Facilities (4160-18B)
	Year 4 Annual Report of Progress: Operating Freeways with Managed Lanes (4160-19B)
	Staffing and Training Needs for Managed Lanes Facilities (4160-20B)
	Decision Framework for Selection of Managed Lanes Strategies (4160-21B)
	Strategies for Interim Use of Managed Lanes (4160-22B)
	Monitoring and Evaluating Managed Lane Facility Performance (4160-23B)
Newsletters	*FastLane* – Fall 2004
	FastLane – Spring 2005
Articles	Managed Lanes: The Future of Freeway Travel, *Institute of Transportation Engineers (ITE) Journal*, February 2005, pp. 22-26
	Managed Lanes Research in Texas, *ITE Journal*, February 2005, pp. 27-31
Abstracts	Analyzing Traveler Information Needs for Managed Lanes, ITE 2005 Technical Conference and Exhibit, August 2004
	Managed Lane Ramp Design Issues, ITE 2005 Technical Conference and Exhibit, August 2004
	Traffic Control Devices for Managed Lanes, 12th International HOV Systems, Pricing, and Managed Lanes Conference, August 2004
	Recent Research on Managed Lanes: A Report from Texas, 12th International HOV Systems, Pricing, and Managed Lanes Conference, August 2004
	Managed Lane Ramp Design Issues, 12th International HOV Systems, Pricing, and Managed Lanes Conference, August 2004
	Enforcement of Managed Lanes with HOV Preference, 12th International HOV Systems, Pricing, and Managed Lanes Conference, August 2004
	Design and Operations Associated with Single Lane Directional Managed Lanes, 12th International HOV Systems, Pricing, and Managed Lanes Conference, August 2004
Presentations	Operating Freeways with Managed Lanes, 2004 PMC Workshop, September 2004
	Operating Freeways with Managed Lanes, 2004 External Stakeholder Meeting, September 2004
	Operating Freeways with Managed Lanes, 2004 TxDOT Transportation Short Course, October 2004
	Operating Freeways with Managed Lanes, Texas A&M University Transportation Graduate Course, November 2004
	Managed Lanes – How Project Objectives Influence Operating Strategy, Capital Area Metropolitan Planning Organization (CAMPO) Technical Advisory Committee Meeting, November 2004
	Managed Lanes, CAMPO Transportation Policy Board, December 2004
	Traveler Information and Traffic Control Device Needs for Managed Lanes, National Committee on Uniform Traffic Control Devices Meeting, January 2005*
	Managed Lanes – An Overview of Current Issues, ITE 2005 Technical Conference, February 2005*
	Analyzing Traveler Information Needs for Managed Lanes, ITE 2005 Technical Conference, February 2005*
	Operating Freeways with Managed Lanes, Texas A&M ITE Student Chapter, March 2005
	Recent Research on Managed Lanes: A Report from Texas, 12th International HOV Systems, Pricing, and Managed Lanes Conference, April 2005*

Table 2-1. Published Project Deliverables and Products (continued).

Type of Product	Description/Title/Event
Fiscal Year 2005 (continued)	
Presentations (continued)	Managed Lane Ramp Design Issues, 12th International HOV Systems, Pricing, and Managed Lanes Conference, April 2005*
	Traffic Control Devices for Managed Lanes, 12th International HOV Systems, Pricing, and Managed Lanes Conference, April 2005*
	Enforcement of Managed Lanes with HOV Preference, 12th International HOV Systems, Pricing, and Managed Lanes Conference, April 2005*
	Design and Operations Associated with Single Lane Directional Managed Lanes, 12th International HOV Systems, Pricing, and Managed Lanes Conference, April 2005*
	Traveler Information and Traffic Control Device Needs for Managed Lanes, International Bridge, Tunnel, and Turnpike Association Facilities Management Workshop, May 2005*
Status Reports	Monthly Status Report – September 2004
	Monthly Status Report – October 2004
	Monthly Status Report – November 2004
	Monthly Status Report – December 2004
	Monthly Status Report – January 2005
	Monthly Status Report – February 2005
	Monthly Status Report – March 2005
	Monthly Status Report – April 2005
	Monthly Status Report – May 2005
	Monthly Status Report – June 2005
	Monthly Status Report – July 2005
	Monthly Status Report – August 2005
Tech Memos	2004 External Stakeholder Committee Meeting Summary (TTI TM 4160-8)
	Single-Lane Issues on Managed Lanes Facilities (TTI TM 4160-21W)
Fiscal Year 2004	
Reports	Proceedings of Annual Workshops for TxDOT (FHWA/TX-04/4160-3) *Meeting Summary: 2003 Annual Project Monitoring Committee Workshop*
	Task 13 Report: Traveler Information Needs (FHWA/TX-04/4160-13) *Identification of Traveler Information and Decision-Making Needs for Managed Lane Users*
	Task 14 Report: Interim Managed Lanes Manual (FHWA/TX-04/4160-14) *Interim Manual for Managed Lanes*
	Task 15 Report: Traffic Control Devices (FHWA/TX-04/4160-16) *Traffic Control Devices for Managed Lanes*
	Annual Research Report: Year 3 (FHWA/TX-04/4160-15) *Year 3 Annual Report of Progress: Operating Freeways with Managed Lanes*
Bulletins	*Identification of Traveler Information and Decision-Making Needs for Managed Lane Users (4160-13B)*
	Year 3 Annual Report: Operating Freeways with Managed Lanes (4160-15B)
	Traffic Control Devices for Managed Lanes (4160-16B)
Newsletters	*FastLane* – Fall 2003
	FastLane – Spring 2004
Articles	Managed Lanes: The Future of Freeways, *TexITE Newsletter*, Summer 2004, pp. 10, 21

Table 2-1. Published Project Deliverables and Products (continued).

Type of Product	Description/Title/Event
Fiscal Year 2004 (continued)	
Abstracts	Managed Lanes Research in Texas, Transportation Research Board (TRB) Third International Symposium on Highway Design, May 2004
Presentations	Operating Freeways with Managed Lanes, 2003 PMC Workshop, September 2003
	Operating Freeways with Managed Lanes, 2003 External Stakeholder Meeting, September 2003
	Operating Freeways with Managed Lanes, Research Management Committee (RMC) 4 Meeting, November 2003
	Managed Lanes: A New Alternative for Freeway Travel, Downtown Austin Alliance Meeting, December 2003
	Managed Lanes, Central Texas Regional Mobility Authority Meeting, February 2004
	Managed Lanes, TxDOT District Engineers Meeting, April 2004
	Value Pricing Implementation, Intelligent Transportation Society of America (ITSA) Annual Meeting, April 2004*
	Operating Freeways with Managed Lanes, RMC 2 Meeting, June 2004
	Operating Freeways with Managed Lanes, RMC 4 Meeting, June 2004
	Operating Freeways with Managed Lanes, TxDOT Urban District Engineers Meeting, June 2004
	Design Considerations for Toll Lanes within Existing Freeways – Recent Findings from Managed Lanes Research, TxDOT Design and Bridge Conference, June 2004
	Signing for Managed Lanes: What Are the Issues and Successful Practices, 2004 ITE Annual Meeting, August 2004*
	Managed Lanes Research in Texas, 7th Annual Texas Transportation Summit, August 2004*
Status Reports	Monthly Status Report – September 2003
	Monthly Status Report – October 2003
	Monthly Status Report – November 2003
	Monthly Status Report – December 2003
	Monthly Status Report – January 2004
	Monthly Status Report – February 2004
	Monthly Status Report – March 2004
	Monthly Status Report – April 2004
	Monthly Status Report – May 2004
	Monthly Status Report – June 2004
	Monthly Status Report – July 2004
	Monthly Status Report – August 2004
Tech Memos	2003 External Stakeholder Committee Meeting Summary (TTI TM 4160-7)
Fiscal Year 2003	
Reports	Proceedings of Annual Workshops for TxDOT (FHWA/TX-03/4160-3) *Meeting Summary: 2002 Annual Project Monitoring Committee Workshop*
	Task 7 Report: Sample State and Federal Legislation (FHWA/TX-03/4160-8) *State and Federal Issues for Managed Lanes*
	Task 9 Report: Funding and Financing (FHWA/TX-03/4160-9) *The Funding and Financing of Managed Lanes Projects*
	Task 10 Report: Geometric Design (FHWA/TX-03/4160-10) *Managed Lane Ramp and Roadway Design Issues*
	Task 11 Report: Enforcement (FHWA/TX-03/4160-11) *Enforcement Issues on Managed Lanes*

Table 2-1. Published Project Deliverables and Products (continued).

Type of Product	Description/Title/Event
Fiscal Year 2003 (continued)	
Reports (continued)	Annual Research Report: Year 2 (FHWA/TX-03/4160-12) *Year 2 Annual Report of Progress: Operating Freeways with Managed Lanes*
Products	Sample State and Federal Legislation (FHWA/TX-02/4160-P3) *Sample State and Federal Legislation*
Implementation	Policy Maker Brochure (4160-5-P1) *Managed Lanes: More Efficient Use of the Freeway System*
	Media Editorial Staff Brochure (4160-6-P2) *Managed Lanes: A New Concept for Freeway Travel*
Bulletins	*Managed Lanes Symposium (4160-1B)*
	Managed Lanes – Traffic Modeling (4160-4B)
	Developing a Managed Lanes Position Paper for a Policy-Maker Audience (4160-5B)
	Developing a Managed Lanes Position Paper for a Media Audience (4160-6B)
	Marketing the Managed Lanes Concept (4160-7B)
	State and Federal Issues for Managed Lanes (4160-8B)
	The Funding and Financing of Managed Lanes Projects (4160-9B)
	Managed Lane Ramp and Roadway Design Issues (4160-10B)
	Enforcement Issues on Managed Lanes (4160-11B)
	Year 2 Annual Report: Operating Freeways with Managed Lanes (4160-12B)
Newsletters	*FastLane* – Fall 2002
	FastLane – Winter 2003
	FastLane – Spring 2003
	FastLane – Summer 2003
Articles	The Future of Freeways: Research Identifies Strategies for Developing Managed Lanes, *Texas Transportation Researcher*, Vol. 39, No. 2, p. 14
	Managed Lanes: A New Concept for Freeway Travel, *The Dunn Deal*, #9, May 2003, pp. 2-3
Published Papers	State Legislative Issues for Managed Lanes in Texas, 2003 TRB Annual Meeting
	Managed Lanes Research in Texas, 2003 ITE Annual Meeting
Unpublished Papers	A Legislative Framework for Operating Managed Lanes, 11th International HOV Conference
	Managed Lane Ramp Design Issues, 2004 TRB Annual Meeting
Abstracts	Managed Lanes Research in Texas, 2003 ITE Annual Meeting
Presentations	Operating Freeways with Managed Lanes, 2002 PMC Workshop, September 2002
	Operating Freeways with Managed Lanes, 2002 External Stakeholder Meeting, September 2002
	Managed Lanes Facilities in Texas, 2002 TxDOT Short Course, October 2002
	A Legislative Framework for Operating Managed Lanes, 11th International HOV Conference, October 2002
	Concept Marketing of Managed Lanes, 11th International HOV Conference, October 2002
	Managed Lanes Design Issues, 11th International HOV Conference, October 2002
	Managed Lanes – Operational Issues and Design Treatments, 11th International HOV Conference, October 2002
	Operating Freeways with Managed Lanes, RMC 4 Meeting, November 2002*
	Managed Lanes in Texas: What Are the Challenges and Opportunities, 2003 TRB Annual Meeting, January 2003*
	Managed Lanes in Freeway Operations, 2003 TRB Annual Meeting, January 2003*
	Managed Lanes in Texas: What Are the Challenges and Opportunities, 2003 TRB Annual Meeting, January 2003*
	Managed Lanes in Freeway Operations, 2003 TRB Annual Meeting, January 2003*
	Weaving Recommendations for Managed Lanes, 2003 TRB Annual Meeting, January 2003*

Table 2-1. Published Project Deliverables and Products (continued).

Type of Product	Description/Title/Event
Fiscal Year 2003 (continued)	
Presentations (continued)	State Legislative Issues for Managed Lanes in Texas, 2003 TRB Annual Meeting, January 2003*
	Involving the Public in a New Concept: Managed Lanes, 2003 TRB Annual Meeting, January 2003*
	Managed Lanes in Freeways Operations, 2003 ITSA Annual Meeting, May 2003*
	Operating Freeways with Managed Lanes, RMC 2 Meeting, June 2003
	Managed Lanes in Texas, Utah Department of Transportation (UDOT) Managed Lanes Video Conference, July 2003
	Managed Lanes Research in Texas, 2003 ITE Annual Meeting, August 2003*
Semiannual Reports	Research Supervisor Semiannual Progress Report – February 2003
	Research Supervisor Semiannual Progress Report – August 2003
Status Reports	Monthly Status Report – September 2002
	Monthly Status Report – October 2002
	Monthly Status Report – November 2002
	Monthly Status Report – December 2002
	Monthly Status Report – January 2003
	Monthly Status Report – February 2003
	Monthly Status Report – March 2003
	Monthly Status Report – April 2003
	Monthly Status Report – May 2003
	Monthly Status Report – June 2003
	Monthly Status Report – July 2003
	Monthly Status Report – August 2003
Tech Memos	2002 External Stakeholder Committee Meeting Summary (TTI TM 4160-6)
Fiscal Year 2002	
Reports	Annual Research Report: Year 1 (FHWA/TX-02/4160-2) *Year 1 Annual Report of Progress: Operating Freeways with Managed Lanes*
	Proceedings of Annual Workshops for TxDOT (FHWA/TX-02/4160-3) *Meeting Summary: 2001 Annual Project Monitoring Committee Workshop*
	Task 5 Report: Analysis of Operational Scenarios (FHWA/TX-02/4160-4) *Managed Lanes – Traffic Modeling*
	Task 8 Product: Developing a Managed Lanes Position Paper for a Policy-Maker Audience (FHWA/TX-02/4160-5) *Developing a Managed Lanes Position Paper for a Policy-Maker Audience*
	Task 8 Product: Developing a Managed Lanes Position Paper for a Media Audience (FHWA/TX-02/4160-6) *Developing a Managed Lanes Position Paper for a Media Audience*
	Task 8 Report: Concept Marketing Strategy (FHWA/TX-02/4160-7) *Marketing the Managed Lanes Concept*
Products	Position Paper for Key Policy Makers (FHWA/TX-02/4160-P1) *Managed Lanes: More Efficient Use of the Freeway System: A Position Paper for Policy Makers*
	Position Paper for Media Editorial Staff (FHWA/TX-02/4160-P2) *Managed Lanes: A New Concept for Freeway Travel: A Position Paper for the Media*

Table 2-1. Published Project Deliverables and Products (continued).

Type of Product	Description/Title/Event
Fiscal Year 2002 (continued)	
Newsletters	*FastLane* – August 2001
	FastLane – December 2001
	FastLane – March 2002
	FastLane – June 2002
Articles	Managed Lanes, *Transportation Management + Engineering*, December 2001/January 2002, p. 5
	Managed Lanes Offer Choices, Flexibility, *Texas Transportation Researcher*, Vol. 38, No. 2, pp. 6-7
Unpublished Papers	State Legislative Isssues for Managed Lanes in Texas, 2003 TRB Annual Meeting
	Weaving Recommendations for Managed Lanes, 2003 TRB Annual Meeting
Abstracts	Concept Marketing of Managed Lanes, 11th International HOV Conference, October 2002
	A Legislative Framework for Operating Managed Lanes, 11th International HOV Conference, October 2002
	Life-Cycle Graphical Representation of Managed HOV Lane Evolution, 11th International HOV Conference, October 2002
	Weaving Lengths for Managed Lanes Access and Egress, 11th International HOV Conference, October 2002
	Managed Lanes in Texas: A New Strategy, 11th International HOV Conference, October 2002
Presentations	Operating Freeways with Managed Lanes, RMC 2 Meeting, November 2001
	Marketing Managed Lanes in Texas, 2002 TRB Annual Meeting,* January 2002
	Managed Lanes Research, 2002 TRB Annual Meeting,* January 2002
	Operating Freeways with Managed Lanes, TxDOT Managed Lanes Project Managers Meeting, March 2002
	Managed Lanes Concept, TxDOT Design Conference, April 2002
	Managed Lanes Concept, Florida Statewide HOV Workshop,* April 2002
	Operating Freeways with Managed Lanes, RMC 4 Meeting, June 2002
	Design Issues Regarding Managed HOV Lanes, AASHTO 2002 Annual Meeting – Subcommittee on Design,* June 2002
	Managed Lane Concept, 2002 Texas Transportation Summit, August 2002
Semiannual Reports	Research Supervisor Semiannual Progress Report – February 2002
	Research Supervisor Semiannual Progress Report – August 2002
Status Reports	Monthly Status Report – September 2001
	Monthly Status Report – October 2001
	Monthly Status Report – November 2001
	Monthly Status Report – December 2001
	Monthly Status Report – January 2002
	Monthly Status Report – February 2002
	Monthly Status Report – March 2002
	Monthly Status Report – April 2002
	Monthly Status Report – May 2002
	Monthly Status Report – June 2002
	Monthly Status Report – July 2002
	Monthly Status Report – August 2002
Tech Memos	Current State of the Practice (TTI TM 4160-4)
	Glossary of Terms for Managed Lanes (TTI TM 4160-5)
	Current State of the Practice (TTI TM 4160-4F)
	Glossary of Terms for Managed Lanes (TTI TM 4160-5F)

Table 2-1. Published Project Deliverables and Products (continued).

Type of Product	Description/Title/Event
Fiscal Year 2001	
Reports	Proceedings of Managed Lanes Symposium (FHWA/TX-02/4160-1) *Managed Lanes Symposium – Conference Proceedings*
Articles	Managed Lanes – The Future of Freeway Travel, *Texas Transportation Researcher*, Vol. 37, No. 2, p. 12
Unpublished Papers	Summary of Updates to the HOV and Park-and-Ride Facilities Design Guides by the AASHTO Subcommittee on Design, 2002 TRB Annual Meeting, August 2001
Presentations	Developing Managed Lanes, 2000 TxDOT Short Course, October 2000
	Operating Freeways with Managed Lanes, RMC 4 Meeting, June 2001
	Operating Freeways with Managed Lanes, 2001 PMC Meeting, August 2001
Semiannual Reports	Research Supervisor Semiannual Progress Report – February 2001
	Research Supervisor Semiannual Progress Report – August 2001
Status Reports	Monthly Status Report – May 2001
	Monthly Status Report – July 2001
	Monthly Status Report – August 2001
Tech Memos	Definition of Managed Lanes – Draft (TTI TM 4160-1)
	Definition of Managed Lanes – Final (TTI TM 4160-2)
	Project Vision and Objective (TTI TM 4160-3)

* Travel for presentation NOT paid for by Project 0-4160.

CHAPTER 3: CRITICAL RESEARCH RESULTS

As a concise review of the project, the following sections provide a summary of the work completed under this contract. They are organized by task and related activities critical to the successful completion of the project. Where appropriate, the authors reference individual research reports related to specific tasks.

DEFINITION OF MANAGED LANES

At the onset of the project, the project director and the program coordinator agreed on a definition for managed lanes. This agreement established a definition that serves as the official definition of managed lanes for the entire TxDOT organization. Thus, with the guidance and consensus of the TxDOT project monitoring committee, the project team established the following as a definition for managed lanes:

> "A managed lane facility is one that increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals."

The definition is very general, and yet it reflects the complexity and flexibility of the managed lanes concept. The definition allows each district across the state to determine what "managed lanes" means for their jurisdiction. Thus, it respects the needs of the community without requiring the application of a specific strategy that does not meet those needs. Moreover, it encourages flexibility, realizing that the needs of a region may change over time, thereby requiring a different managed lane operational strategy.

REVIEW OF CURRENT PRACTICE AND STATE-OF-THE-PRACTICE LITERATURE

The research team conducted an extensive and exhaustive review of current practice and related research on the operation of managed lanes in areas throughout the country and around the world. Based on over 100 documents published over the past 20 years, the review highlighted key managed lanes operational strategies currently in use. These strategies include:

- HOV lanes,
- HOT lanes,
- value-priced facilities,

- exclusive lanes (e.g., busways and truck lanes),
- separation and bypass lanes,
- dual facilities, and
- lane restrictions.

Furthermore, the review brought to light key issues regarding the implementation of managed lanes, such as:

- operational issues,
- safety,
- economics,
- legal and policy issues,
- environmental concerns,
- social and public opinion issues, and
- enforcement.

The results of this task created an overall framework for the research planned for the project. They identified the operational strategies available to agencies and drew attention to the various issues that agencies need to address when considering a managed lane facility. The complete text of this literature review and its associated references are published as Appendix A within Report 0-4160-2: *Year 1 Annual Report of Progress: Operating Freeways with Managed Lanes* (*1*).

GLOSSARY OF TERMS

During the course of the review of current practice, it became evident to the researchers that managed lanes are a complex concept with an equally complex lexicon of terms. The research reports and documents indicated that the consistent use and meanings of terms, phrases, and concepts are lacking. This inconsistency has the propensity to confuse readers and generate questions when discussing specific issues or operational strategies for managed lanes.

To eliminate potential confusion and to clarify the intended course of the research project, the research team compiled a glossary of terms related to managed lanes that emerged from other TTI work. The terms included came from a glossary developed for TxDOT's Austin District as part of its HOV planning work and from a pricing glossary under development by the TRB pricing subcommittee. This glossary served as a framework upon which researchers based their efforts. Appendix B of Report 0-4160-2: *Year 1 Annual Report of Progress: Operating Freeways with Managed Lanes* contains the complete list of terms related to managed lanes (*1*).

MANAGED LANES SYMPOSIUM

To kick off the project, the research team and TxDOT sponsored the Managed Lanes Symposium to begin generating a dialogue among all potential partners and to provide insight into the concerns of those partners regarding operation of managed lanes. The intent was for the symposium to serve as a starting point for continued movement toward using managed lanes to maximize capacity on congested roadways and enhancing the mobility of the transportation user.

The symposium assembled over 90 key staff, decision makers, and other related stakeholders from transportation agencies across Texas to discuss issues pertinent to the planning, design, and operation of managed lane facilities. The attendees gained insight from experts around the country who provided current thinking about managed lane operations.

Guest Speakers and Panelists

Several key panelists provided information relative to the national perspective and local experiences. The intent was to provide a full perspective on the issue of managed lanes and to establish a basis of knowledge for generating discussion during the afternoon breakout sessions.

The first panelist, Dr. Kiran Bhatt with KT Analytic, Inc., provided an update on managed lanes projects across the country, focusing on the following four operational strategies:

- HOV facilities,
- HOT lanes,
- variable-priced lanes, and
- fast and intertwined regular (FAIR) lanes.

After briefly discussing these four strategies, Bhatt noted that agencies considering managed lanes facilities should first consider several issues such as design constraints, enforcement, equity, and determining criteria for success. The recipe for success is:

- the demonstrated need for the project,
- forward-looking planners,
- careful design,

- responsiveness to user concern, and
- prospects for self-sufficiency.

Bhatt noted that even if projects do not prove to be self-sufficient, they might still be worthwhile given alternatives such as new construction.

Sally Wegmann, P.E., director of Transportation Operations for the TxDOT Houston District, gave a brief overview of the history of innovative mobility strategies in the Houston region. She reflected back to 1974 when departments of transportation called HOVs transit ways and the lanes were intended to provide a free-flow lane for buses and carpools consisting of eight or more persons. Today, HOV lanes in Houston currently allow a minimum of two persons. The HOV lanes are highly successful at moving people from the suburbs to the central business district. However, as demand increases and the general lanes become more congested, the district must examine ways of responding. As a result, TxDOT is testing a HOT lane approach on the IH-10 corridor and on US 290 to assess feasibility. TxDOT must then examine ways to increase marketing and to identify other target groups and modes that need to be developed, including:

- trucks,
- congestion pricing on general lanes, and
- express lanes that can be served as efficiently as the HOV lanes are being served.

George Beatty, Jr., division president of the Greater Houston Partnership, gave the perspective of managed lanes from the community at large. He expressed his belief that Houston is a transportation laboratory and that there are many scientists managing the project. He also stressed that transportation professionals must establish what the Houston transportation system is designed to accomplish. No longer can transportation professionals respond to congestion by building a road. Now, transportation professionals and community leaders need to consider other issues, including environmental concerns. Beatty suggested we think of HOT and HOV lanes not as individual units, but as a part that must fit into the whole. Transportation and system-wide benefits must be enumerated to both users and non-users.

Matthew MacGregor, P.E., LBJ project manager for the TxDOT Dallas District, spoke on managed lanes and the LBJ Freeway in Dallas, Texas. The project is 21 miles long and includes tunnels and multiple points of access. The challenge is to balance the trip patterns. LBJ has peak traffic hours for 12 hours a day, and traffic continues to grow during non-peak hours.

Traffic is increasing on arterial street systems, as well. Current options include main lanes with four HOV lanes, main lanes with four HOV lanes and express lanes, and main lanes with six HOV lanes. MacGregor cited numerous reasons for managed lanes, such as safety, predictability, air quality, and mobility. Other issues critical to the LBJ managed lane project include:

- multiple access points,
- signing,
- tunnels,
- pricing,
- occupancy detection,
- electronic collection, and
- ticketing by mail.

He also emphasized the importance of the regional plan and the inclusion of bus rapid transit as part of the managed lanes considerations.

Glenn McVey, P.E., congestion management engineer for the TxDOT Austin District, and Chuck Fuhs, AICP, deputy project manager with Parsons Brinckerhoff, Inc., gave the Austin perspective on managed lanes. McVey began by discussing the status of HOV studies in Austin that include long-range and interim HOV operations for three roadway categories (Loop 1, IH-35, and arterials) and the possibility of HOT lanes. TxDOT will build several freeway sections currently under construction with the ability to retrofit with HOV or managed lanes. A reversible HOV is planned for IH-35, which has a high directional distribution. Fuhs focused on the characteristics of Loop 1, which has high two-directional demand with high levels of congestion. Concepts screened for this facility include managed lanes at grade, elevated, or in depressed sections and designed for limited access. A key area is the intersection of Loop 1 and US 183, a design that provides direct access into transit support systems, the downtown street system, and other key points. Thus, according to Fuhs, access management would be key to regulating flow and balance demand, perhaps through tolling if necessary.

Dan Lamers, P.E., principal transportation engineer with the North Central Texas Council of Governments, discussed managed facilities in north central Texas. He highlighted the benefits of managed facilities, which are:

- travel time savings,
- travel cost savings,
- generation of revenue,
- maximizing capacity and efficiency for the corridor and the facility,
- maintaining acceptable levels of service (again for the entire corridor), and
- maintaining operational flexibility.

Key operational issues to consider include how engineers can adapt an HOV lane to a managed facility or how to better manage a toll road (already a managed concept). Lamers also stressed the importance of recognizing the viewpoints of other stakeholders and that managed facilities must provide additional modal options, particularly in light of environmental equity and other planning issues. He encouraged listeners to maintain sight of goals, stating that we are not just moving vehicles or people. According to Lamers, we want to connect origins with what people want to do with their lives. He also encouraged the audience to focus on technology to ensure the technology moves in a direction to support long-term goals.

Peter Samuel, editor for *Toll Roads Newsletter*, spoke on demonstrating managed lanes' benefits to constituents. He stressed that community leaders and transportation professionals should not suppress the truth when discussing improvements or changes to the transportation system. Such thinking is critical for managed lanes. Samuel stressed that consummate leadership focuses on a single objective when using eloquent, well-chosen words. Further, he posed a challenge regarding the term "managed lanes," as the term implies that other lanes are not managed.

Interactive Breakout Sessions

The second half of the symposium consisted of concurrent breakout sessions. During these interactive workshop sessions, attendees participated in one of three separate groups to discuss managed lanes issues and determine priorities. A facilitator and a scribe liaison coordinated each session and helped the flow of dialogue to occur efficiently. In these sessions, the facilitator asked attendees to identify their most important issues associated with managed lanes. Each facilitator reviewed a potential list of issues as a starting point. Groups were asked to add, modify, and supply subcategories to the initial discussion list. The initial list included the following:

- design standards/access,
- eligible users/user groups,
- technology/interoperability,
- performance and evaluation,
- public awareness,
- equity,
- enforcement/operations,
- legislative requirements/regulatory, and
- funding/financing.

Participants brainstormed the list of pertinent issues surrounding planning, constructing, implementing, and operating managed lanes. Thereafter, attendees identified their top five issues from among those on the list. Leaders structured groups to reflect the range of organizations and TxDOT divisions represented by attendees to foster discussion, exchange ideas, and appreciate different views on transportation concerns. The interesting result was that each group arrived at a similar list of critical managed lanes issues, as presented in Table 3-1. Other issues discussed, but not ranked, included:

- equity,
- private institutional issues,
- private/public partnerships, and
- affordable transit access.

Table 3-1. Key Issues from Interactive Breakout Sessions.

Group 1	Group 2	Group 3
Eligibility and User Groups Design Standards/Access Public Awareness Enforcement Operations Legislative Requirements Funding/Financing Marketing Performance and Evaluation	Public Awareness Design Standards Performance/Evaluation Eligibility/User Groups Funding/Financing & Enforcement/Operations	Enforcement/Operations Public Awareness Technology/Inoperability Legislative Requirements/Regulatory Design Standards/Access

Research Recommendations

The research team was extremely pleased with the inaugural Managed Lanes Symposium. As evidenced by the large number of attendees, managed lanes are a major issue that urban areas across Texas and the country are considering for help in maintaining mobility. The results from the symposium, particularly from the breakout sessions, helped the research team direct the project so that they addressed the major issues and concerns of stakeholders over the course of the project. Report 0-4160-1: *Managed Lanes Symposium: Conference Proceedings* contains the complete proceedings of the symposium (*2*).

ANALYSIS OF OPERATIONAL SCENARIOS BASED ON USER GROUP

The purpose of this task was to demonstrate the impacts of alternative operating strategies on design and traffic operations considerations. Using planning-level vehicle demands and trip characteristics available to TTI staff, the corridor study team developed a simulation model to evaluate factors such as:

- access design,
- access spacing, and
- geometric design to provide insight into:
    - signing,
    - delineation, and
    - traveler information needs.

Researchers used the results to provide both corridor-specific and general managed lane implementation guidelines.

Project Effort

Researchers selected the VISSIM model for this project from among several traffic models capable of performing detailed modeling of managed lanes within freeway corridors. A VISSIM model of the Katy Freeway corridor in Houston, Texas, was then created as a platform for an analysis of the frequency and location of at-grade (i.e., from within the freeway) access points for managed lanes. Researchers identified several key issues (not fully documented in current analytical practices and guidelines) that have a bearing on managed lanes operation. These issues, as illustrated in Figure 3-1, are:

- freeway weaving from a freeway entrance to a managed lane entrance,
- freeway weaving from a managed lane exit to a freeway exit, and
- intra-freeway vehicle stream separation of vehicles destined for managed lane access.

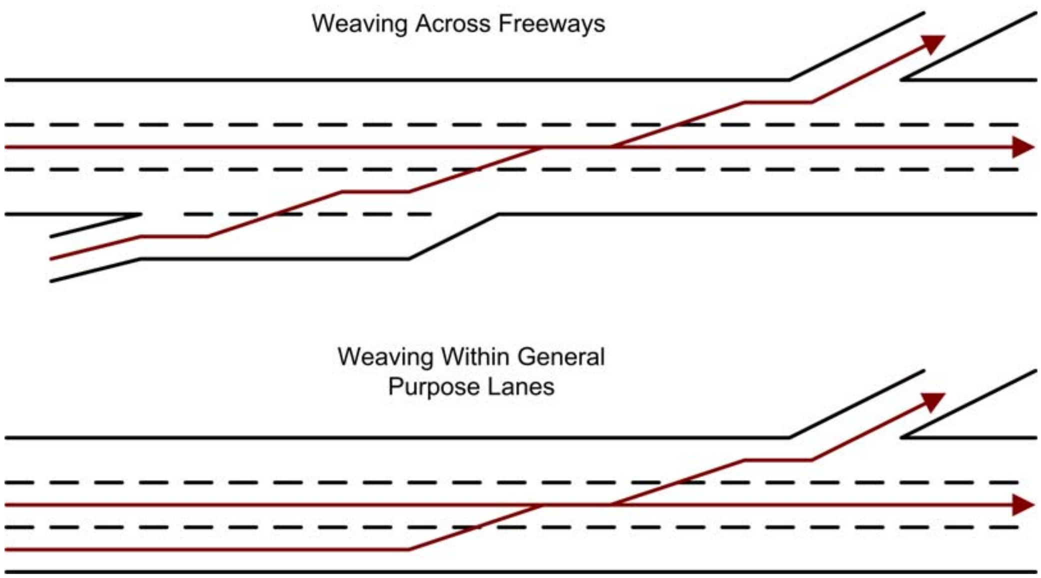

Figure 3-1. Complex Managed Lanes Weaving.

For each of these key issues, VISSIM models were constructed to examine different combinations of freeway volume level, percentage of weaving vehicles, weaving distance, and weaving complexity. In total, over 650 combinations of weaving distance, weaving complexity, and traffic volume conditions were designed into modeling experiments, and over 2000 simulations were performed.

Key Findings

For freeway weaving across five lanes between a standard, right-side freeway entrance ramp and a left-side managed lane entrance ramp, modeling indicates that the impacts of heavy vehicles in the vehicle stream are more pronounced at shorter weaving distances. Freeway operation tended to stabilize at weaving distances greater than 3000 feet for medium volume levels and 3500 to 4000 feet for high freeway volume levels. When locating an intermediate ramp between the freeway and managed lane entrances, operation stabilized at weaving distances greater than 3500 feet for moderate volumes and 4000 feet for high volumes.

For freeway weaving across three lanes between a left-side managed-lane exit and a right-side freeway exit ramp, modeling indicates that weaving and non-weaving freeway operations tend to stabilize at weaving distances greater than 3000 feet for medium volumes and 3500 feet for high volumes. In more complex exit ramp simulations, where an intermediate entrance ramp was located between the managed lane exit and the freeway exit ramp, weaving and non-weaving flow stabilized for a four-lane weaving section at distances greater than 3000 feet.

Intra-freeway weaving for accessing managed lanes is the "sorting" of vehicles destined for the managed lanes into the leftmost freeway lane. This maneuver can be viewed as the weaving distance required for a driver who has decided he/she is a candidate for using the managed lanes to reach the correct lane for a transition into the managed portion of the freeway facility. Consistent with expectations, greater selective separation weaving distance exhibits improved performance. Also as expected, non-weaving speeds are consistently higher than weaving speeds, as the non-weaving – or through – vehicle population was not required to discover and maneuver into gaps in adjacent lanes in order to reach the leftmost, managed facility access lane. For medium volume levels, selective separation results stabilize at distances greater than and equal to 1 mile. For high volume levels, selective separation results stabilize at distances between 1.5 and 2 miles and greater. Impacts of truck percentage on performance were determined to be more substantial than the impact of bus percentage. Again, such results were expected, as the truck vehicle class is both larger and slower than buses to accelerate/decelerate.

Research Recommendations

Standard analysis techniques, especially the *Highway Capacity Manual (HCM)* (*3*) and Highway Capacity Software (HCS) (*4*) are appropriate for isolated entrance, exit ramp, and one-sided weaving section analysis where researchers must study these features within corridors with managed lanes applications. More complex issues, such as cross-freeway weaving and intra-freeway weaving, are most appropriately and practically studied using simulation.

The simulation tools CORSIM and Integration offer sufficient data input flexibility to accommodate a variety of managed lane simulation modeling issues, including complex geometrics, signalization/control, and some routing capabilities. However, where multiple vehicle classes and selective real-time control and routing must be modeled, the simulation tools Paramics and VISSIM are most applicable.

Typical managed lanes design guidelines specify either minimum (500 feet) and desirable (1000 feet) weaving distances per lane, or a preferred minimum distance (2500 feet) between a freeway entrance or exit and a managed lanes facility entrance or exit. The current research updates and places conditionality on these generic guidelines. A recommended weaving distance application table has been developed for anticipated conditions in the design year (see Table 3-2). The managed facility designer has the option of:

- specifying medium or high volume in the design year (based on *HCM* level of service [LOS]),
- allowing for or not allowing for up to a 10-mph reduction in operating speed due to managed lane-related weaving, and
- having or not having intermediate ramp/ramps between the freeway entrance/exit and managed lanes entrance/exit.

Table 3-2. Weaving Distances for Managed Lane Cross-Freeway Maneuvers.

Design Year Volume Level	Allow up to 10-mph Mainlane Speed Reduction for Managed Lane Weaving?	Intermediate Ramp (between Freeway Entrance/Exit and Managed Lanes Entrance/Exit)?	Recommended Minimum Weaving Distance per Lane (feet)
Medium (LOS C or D)	Yes	No	500
		Yes	600
	No	No	700
		Yes	750
High (LOS E or F)	Yes	No	600
		Yes	650
	No	No	900
		Yes	950
Note: The provided weaving distances are appropriate for freeway vehicle mixes with up to 10 percent heavy vehicles; higher percentages of heavy vehicles require increasing the per-lane weaving distance. The value used should be based on engineering judgment, though a maximum of an additional 250 feet per lane is suggested.			

For general managed lanes planning purposes, the recommended minimum and desirable distances between a freeway entrance/exit ramp and a managed lanes entrance/exit are 2500 feet and 4000 feet, respectively. The minimum distance applies in cases where a speed reduction of up to 10 mph is acceptable and freeway volumes are moderate. For high freeway volumes, especially in cases where an intermediate ramp is present between the freeway entrance/exit and the managed lanes entrance/exit, 4000 feet of cross-freeway weaving distance is appropriate.

Under moderate volume freeway conditions (i.e., LOS C or D), researchers recommend a maximum weaving volume of 450 vehicles per hour between any given freeway entrance and the next downstream managed lanes entrance (and conversely, for any given managed lanes exit and the next downstream freeway exit). Under high volume freeway conditions, a maximum weaving volume of 350 vehicles per hour is recommended for the same conditions. In corridors where freeway ramp location, spacing, and origin-destination patterns cause managed lane-related weaving volumes that exceed these values, it is recommended that direct access from park-and-ride/transit facilities to the managed lanes be provided.

To preserve freeway quality of service in the vicinity of managed lanes entrance and exit ramps, it is recommended that for moderate freeway volumes in the design year, a transition distance of 1 mile be allowed for vehicles to selectively maneuver from their initial position in any freeway lane to the leftmost (or rightmost) freeway lane so that they can access a managed lane facility. Under high volume freeway conditions in the design year, a transition distance of 1.5 to 2 miles is appropriate. For both moderate and high volume freeway conditions, the presence of ramps within the transition distance requires increasing the given value. Note that these distances are the required transition distances once drivers have already determined whether or not they are candidates for the managed facility. Engineers should design sign locations based on driver perception and decision distances that are added onto the values given here. Also note that the transition distance values given here provide sufficient upstream warning so that mainlane speeds do not significantly impact the selective separation weaving vehicles; using lesser transition distances will reduce mainlane and weaving vehicle speed. Report 0-4160-4: *Managed Lanes – Traffic Modeling* contains the complete results of this research task *(5)*.

CONCEPT MARKETING STRATEGY

Public acceptance plays a critical role in the success of any project. Marketing a new product or concept can be challenging. Effective marketing campaigns must consider the goals of the project and tailor the message to meet those goals. Transportation agencies can use several different techniques to communicate with the public depending on the message they wish to deliver and their objectives. Likewise, a message may be tailored to particular audiences. It is important that the public, or the audience, be correctly defined. Audiences depend on the nature or scope of the project and may change throughout the different phases of the project.

Project Effort

Currently, there is no one facility in operation that embraces the complete range of managed lane strategies. There are, however, several unique projects putting lane management into practice by using one or more of the above strategies. Researchers found a number of recently completed managed lanes feasibility studies that address public perception and marketing.

The researchers reviewed selected projects to focus attention on the newer concept of pricing separate travel lanes, including HOT lanes and traditional toll lanes, since previous research addressed marketing and gaining public support for HOV lanes, single occupant vehicle (SOV) lanes, and truck lanes. The goal in reviewing these types of projects was to gain an understanding of public perception and public interaction when introducing an unfamiliar and complex concept for managing travel demand.

This review of managed lane facilities worked to answer the following questions:

- What messages about managed lanes were communicated to the public, and how did they relate to the goals of the project?
- How were the messages communicated?
- Who were the target audiences?
- What was initial public perception?
- How was perception measured?
- Has perception changed since the project was implemented?
- What are the best approaches for communicating project goals and gaining acceptance?
- What lessons can we learn from the national project experience that will assist TxDOT in both communicating the managed lane concept in Texas and in developing public support at the project level?

The researchers examined several projects currently in operation to answer these questions. These projects included:

- State Route 91 in Orange County, California;
- IH-15 in San Diego, California;
- IH-10 (Katy Freeway) in Houston, Texas; and
- Tappan Zee Bridge in Westchester County, New York.

Additionally, researchers also reviewed a number of feasibility studies because of the documented market research efforts. These studies were as follows:

- IH-394 in Minneapolis/St. Paul, Minnesota;
- Regional Pricing Study in Portland, Oregon;
- US 50 HOT Lane Study in Maryland;
- South Florida HOT Lanes Study;
- IH-405 in Seattle, Washington; and
- Value Express Lanes Feasibility Study in Denver, Colorado.

Key Findings

Pricing in particular, and other operational actions in general, can be used as mechanisms to regulate demand on a managed lane facility. When coupled with a comprehensive transportation plan the strategies can be very effective. Studies indicate that when certain factors, such as severe congestion, are present and prevalent issues, such as revenue use, toll collection, and long-range planning are addressed, the likelihood of a project's success increases.

Public involvement has become an important step in the project planning process. However, when considering a managed lanes project, public involvement must go one step further and include a more comprehensive public education component. In this regard, public education differs from public involvement in that people are unfamiliar with the concept. Transportation agencies must thoroughly communicate all aspects of the project, and it must include information such as:

- goals,
- objectives,
- operations, and
- revenue use.

While the public is familiar with some examples of pricing to manage demand, many do not see the government's role in this endeavor. Research shows that in focus groups, individuals are more supportive of the concept after they are shown examples of successful projects and how they operate.

Public education should be a consideration at the first stage of planning a project. The decision-making process should involve all interested parties, and efforts should be made to contact known stakeholders as well as non-traditional stakeholders who may have a vested interest in a project. These groups may include:

- the trucking industry,
- environmental groups,
- alternative fuel proponents, or
- energy conservation groups.

Involving representatives from all affected and potentially affected groups cultivates an education process that carries through all stages of the project. This effort also prevents the spread of misinformation and capitalizes on the interaction between different groups.

Research shows that public education can alleviate concerns about the equity of a project. Pricing projects have been seen as unfair to economically disadvantaged groups when originally presented to the public. However, after a project and its operation are explained, many of the equity questions disappear. Additionally, studies of managed lane use indicate that users represent a fairly even distribution of economic and social groups.

Furthermore, identifying a project champion is also crucial to the success of a project. Research finds that successfully implemented projects have had a strong advocate. Agencies can use this person as a spokesperson in the education process. Although transportation agency representatives or local elected officials might seem the most likely candidates to move a project to public acceptance, the mistrust of politicians and governmental agencies may require a champion to emerge from elsewhere. Public opinion of elected officials and other politicians will help discern whether or not an elected official can effectively communicate the managed lane project message. Therefore, it is important to involve as many potential stakeholders as possible because a champion may arise from any group. For instance, Portland formed a citizen’s committee to explore pricing. The metropolitan planning organization (MPO) felt that since pricing was such a controversial issue, a citizen’s committee would provide a more credible and independent voice to the general public.

Research Recommendations

After a transportation agency identifies a project champion and the public education process begins, the key messages of the project need to be communicated to the general public. Successful projects have common messages that have been well received by the public. These include:

- *Choice* – Research shows that the public does not perceive pricing as inequitable when it is presented as a choice for commuters. The education process is key to communicating this message.
- *Tool* – The public may perceive a pricing project as a "band-aid" or short-term solution. Messages should emphasize that it is only one tool that works with a comprehensive plan.
- *Efficiency* – Typically the public does not understand techniques that may be used to maximize HOV lane utilization. When shown that pricing maximizes available capacity, the pricing concept is more acceptable.
- *Operations* – People want to know how the program will work. Presenting examples of successful projects and how they operate helps facilitate understanding and support. This is especially true in areas where there are no HOV lanes or toll roads. People need assurances that toll collection will not impede travel that is already congested because they may be unfamiliar with electronic toll collection.
- *Enforcement* – Enforcement is especially important in areas that currently operate HOV lanes. The traveling public wants to know that if they pay for a premium service, others will not be allowed a "free ride."
- *Revenue Use* – The agency must clearly define how they plan to use the revenue from the outset of the project. Successful projects have targeted the money for improvements in a corridor where the project is occurring. Public opinion research indicates that people are evenly split on revenue use for transit improvements or roadway projects. Additionally, as part of ongoing public information, improvements that are made with revenue should be highlighted.
- *Transportation Funding* – Research shows that the public is unaware of how states fund transportation projects. Where pricing is used, messages should focus

on the funding shortfall and show pricing as a means to raise revenue for projects that otherwise might not be funded. This method reinforces the idea that a pricing project is a management tool in a comprehensive plan that will impact the entire region.

Research Products

The research resulted in the publication of two reports that documented the findings of the research that was used in the development of two position papers. These reports are TxDOT Report 0-4160-5 (*6*) and 0-4160-6 (*7*). The team also published a position paper for a media audience (*8*) and a position paper for a policy-maker audience (*9*) as a result of this research. The media audience position paper is incorporated into the website as an aid in defining managed lanes (http://managed-lanes.tamu.edu/about/definition.stm).

Researchers also implemented both papers by developing them into user-friendly formats and distributing them to the respective audiences. The products (*10*, *11*) were distributed to:

- elected officials,
- board and commission members,
- executives of public agencies,
- TxDOT personnel,
- cities,
- counties,
- transit authorities,
- metropolitan planning organizations,
- newspaper editorial boards,
- television and radio news directors, and
- magazine editors.

IDENTIFY STATE AND FEDERAL LEGISLATIVE CHANGES OR REQUIREMENTS NEEDED

Perhaps one of the more critical and fundamental components of any managed lane project is the ability for a state or local jurisdiction to legally operate a roadway using a specific managed lane operational strategy. The operation of different types of managed lanes may be sufficiently different from typical freeway operation that it requires changes in legislation and/or regulation. If transportation agencies pursue additional and more complex facilities, then appropriate legislation should be in place.

Research Effort

The goal of this task was to identify key legislative or policy changes necessary to facilitate the various managed lane operational strategies with respect to design, operation, enforcement, and other key issues governing their use. Issues explored include:

- federal, state, and local legislative or policy changes required to design, operate, and enforce managed lanes under a variety of control scenarios and
- legal/regulatory flexibility needed to make appropriate operational and eligibility changes over time as conditions change.

Researchers first put together a summary of all federal and Texas legislation that has an impact on the legality of operational strategies for managed lanes. Those operational strategies addressed include:

- HOV lanes,
- value-priced and HOT lanes,
- exclusive lanes,
- separation and bypass lanes,
- dual facilities, and
- lane restrictions.

Researchers also investigated enforcement and operational flexibility. The focus was only on legislation authorizing the operation of managed lane strategies on various roadway categories. They did not include legislation associated with funding and financing managed lanes that was addressed in a separate task, the results of which are discussed later in this report.

Researchers then looked at the specific laws and statutes to identify legislation that might help facilitate managed lane operational strategies in Texas. In some instances, the existing legislation met the needs of TxDOT and needed no changes. In other instances, researchers found gaps in the legal code or statutes; if filled, they could provide TxDOT with the authorization to operate the entire gamut of managed lane scenarios with flexibility for operational changes over time.

Finally, the research team recommended changes to federal and state legislation that could help advance managed lanes issues. Some recommended changes were minor, but others needed entire new sections to address major gaps in the laws.

Key Findings

Current federal legislation is sufficient to enable TxDOT to establish all types of managed lane facilities on:

- the interstate highway system in Texas,
- state and county highways, and
- local streets.

Regulations regarding operational changes are also in place to guide TxDOT in the creation and long-term operation of such facilities. However, value-priced lanes, HOT lanes, and tolling to finance reconstruction or improvements are only possible through limited pilot programs established by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) (*12*) and the Transportation Equity Act of the 21st Century (TEA-21) (*13*). For these operational strategies to become widespread in the United States, support for a larger and more permanent program needs to be provided at the federal level.

Current Texas legislation provides for the operation of certain managed lanes scenarios. However, in some instances, the legislation is limited or nonexistent. Table 3-3 provides a summary of the various changes the research team recommended. While the changes needed were not numerous, they were considered critical to the long-term success of managed lanes in Texas. Highlights of some of the recommended changes follow.

Managed Lanes

Texas legislation provides TxDOT with sufficient authority to design, construct, operate, or maintain dedicated HOV lanes on any multi-lane highway on the state highway system for the purpose of helping relieve traffic congestion. Currently, this legislation only defines and authorizes HOV lanes and value-priced lanes. Since managed lanes encompass these two operational strategies but can include more, TxDOT would benefit from adding a definition for the term “managed lanes,” thereby incorporating it into the authorization of congestion mitigation projects and facilities.

Table 3-3. Recommended Texas Legislation Changes.

Managed Lane Category	Operational Scenario	Principal Governing State Regulation Needing Changes or Additions
Managed Lanes	All	TTC [1,3]
HOV	All	Sec. 224.153(a) TTC
Exclusive	Truck	TTC [3]
Separation/Bypass	Truck	TTC [3]
Lane Restrictions	State	Sec. 201.901(a) TTC Sec. 621.006 TTC
	Municipality	Sec. 545.0651 TTC
Managed Lane Violation	State	Sec. 224.155 TTC
Enforcement	State	TGC [2]
Operational Changes	All	TTC [3]

[1] Texas Transportation Code
[2] Texas Government Code
[3] No Specific Regulation Currently Exists, New Regulation Needed

HOV Lanes

Current Texas legislation allows inherently low-emission vehicles (ILEVs) to use HOV lanes, which is allowed at the federal level in TEA-21. Since the number of ILEVs currently in operation in the United States and Texas is extremely small, their impact on HOV systems is virtually undetectable. However, it is reasonable to expect that the number of ILEVs will grow steadily as more vehicle manufacturers design them and offer them for purchase. Thus, Texas may need to revisit this legislation in the future to ensure that the use of HOV lanes by single-occupant ILEVs does not adversely impact the operations of the HOV facility.

Related to ILEV use of HOV lanes is the emerging issue of concern where states allow hybrid vehicles with only one occupant to use HOV lanes. In 2000, Virginia began to exempt hybrid vehicles from the occupancy requirements for the state's HOV lanes *(14)*. In 2001, Arizona requested FHWA to allow hybrids to use their HOV lanes, but a policy memorandum released in December of that year stated that hybrid vehicles do not qualify as ILEVs because their engines have fuel vapor emissions. FHWA's position was that allowing them to use HOV lanes with only one occupant is a violation of the federal code and Environmental Protection Agency (EPA) regulations *(15)*. The California Assembly passed a bill in 2004 allowing hybrid vehicles to use the state's HOV lanes *(16)*, but the bill has yet to go into effect pending approval from Congress *(17)*.

In addition to FHWA's interpretation of the federal code as it relates to hybrid vehicles, the general concern regarding allowing hybrid use of HOVs is the increased congestion and delays they may cause to the lanes themselves. The number of hybrid vehicles on the road is steadily increasing, and carpoolers in Virginia are beginning to notice an increase in single-occupant hybrids on the HOV lanes, resulting in an increase in congestion on their daily commutes *(18)*. The reauthorization bill passed by Congress allows states to permit such vehicles to use HOV facilities if they pay a toll for that use. They also have the ability to limit or discontinue allowing their use if their presence degrades the operation of the facility *(19)*.

Value-Priced Lanes and HOT Lanes

The current legislation in place in Texas is sufficient regarding value-priced lanes or HOT lanes. Texas statutes already authorize TxDOT to charge a toll for the use of one or more lanes of a state highway facility, including an HOV lane, thereby permitting TxDOT to participate in the federal value-pricing program.

Exclusive Lanes

Texas statutes allow the Texas Transportation Commission to designate and TxDOT to finance, design, construct, operate, or maintain one or more lanes of a state highway facility as exclusive lanes *(20)*, particularly for the purpose of enhancing safety, mobility, or air quality. Additionally, these lanes may be tolled under certain circumstances, and these exclusive lanes can be designated for different classes of motor vehicles *(21)*.

Separation and Bypass Lanes

Any separation or bypass facility designated for buses or HOVs in Texas would fall under those laws governing HOV lanes. Once again, Texas has no specific statutes that govern the establishment of separation or bypass facilities for trucks. However, the legislation recommended for the creation of exclusive lanes would be appropriate support for separation and bypass lanes.

Dual Facilities

Any managed lane facility using the dual operational concept in Texas falls under the jurisdiction of the state laws governing the specific strategies used by the operating entity, making any specific legislation regarding dual facilities unnecessary.

Lane Restrictions

Texas state statutes authorize municipalities, counties, and TxDOT to establish lane restrictions on facilities on certain portions of the designated state highway system *(22, 23)*. As the Texas statute shows, the wording of such legislation should be such that select vehicles are allowed to use more than one lane of a facility. Such wording can help reduce the likelihood that the motor carrier community will not support the restrictions. Moreover, allowing full-time restrictions is critical to maximizing the effectiveness of lane restrictions on mobility. Lawmakers should write all state-level legislation such that is does not violate the aforementioned federal regulations regarding motor carrier transport.

Managed Lane Violation

Currently, sufficient legislation and legal channels exist with which operating authorities can issue citations for managed lane violations. However, no single law covers all operating strategies on a statewide level. A law that addresses the violation of any managed lane facility in operation in Texas would help ensure that all managed lane strategies become widespread across Texas.

Enforcement

Legislation in Texas sufficiently addresses the need for managed lane enforcement, depending on which authority has the jurisdiction to employ or contract with law enforcement personnel to enforce appropriate laws governing the unlawful use of their respective managed lane facilities, so long as the appropriate laws are in place prior to operation.

Operational Changes

An important feature of managed lanes is the flexibility to change the operational strategy of the facility to better meet the goals of the region it serves and maximize the benefits to its users and the impact on the transportation system as a whole. Therefore, TxDOT needs the authority to make operational changes when deemed appropriate.

Research Recommendations

Incorporating these recommended changes into the Texas statutes broadens the powers of TxDOT and other transportation organizations and provides them with the tools they need to successfully implement managed lane facilities in their jurisdictions in the most effective manner, thereby working to reduce congestion and enhance the mobility of Texans. The complete results of this research task are contained in Report 0-4160-8: *State and Federal Legislative Issues for Managed Lanes* (*24*).

Implementation Status

Texas House Bill (HB) 1208 relating to the mitigation of traffic congestion on highways was signed into law by Governor Rick Perry on 20 June 2003. The HB specifically includes wording regarding exclusive lanes and restricted lanes and addresses many of the issues brought forth in this research.

FUNDING AND FINANCING OF MANAGED LANES

A critical issue facing transportation officials today is the manner in which they can fund and finance these innovative facilities. The unique operating strategies on these facilities offer opportunities for innovative financing techniques that are new and untried in the transportation arena.

Research Effort

Researchers explored funding and financing techniques used to implement current projects that put lane management into practice. The intent was to investigate these particular projects along with funding mechanisms that may be available for use in future projects.

The research team highlighted the financial aspects of implementing managed lanes projects and the applicability of innovative financing techniques to various types of projects. The report describes various financing and funding strategies for given managed lane project scenarios in an effort to help answer the following questions:

- What is the purpose of the managed lanes project?
- How is project construction financed?
- How are maintenance and operations funded?
- What is the extent, if any, of private sector involvement?
- What are the financial terms of the project?
- What institutional, legislative, or policy issues need to be addressed?
- What lessons can be learned from the financing and funding of implemented projects that will assist TxDOT in determining the most effective means of bringing necessary projects to fruition?

Key Findings

In addition to the traditional pay-as-you-go method of reimbursement, many new funding and financing techniques exist today. Often managed lanes projects are large, complex projects, requiring the state department of transportation (DOT) to obligate funds for several years before a project even begins. As a result other projects may be pushed back even further in the funding pipeline. To help ease this burden on transportation departments, the federal government has made available many new techniques for financing and funding projects. These new methods can generally be divided into two categories: cash management tools, and credit enhancement and/or investment tools. Figure 3-2 represents how some of the funding mechanisms may be used for different types of projects. The shaded area indicates that managed lanes projects can encompass each of the three broad categories of marketable revenue projects, revenue projects that require assistance, and traditional non-revenue projects.

As the pyramid indicates, most projects fall into the traditional non-revenue category that requires typical grant funding for their implementation. Only a very small percentage of projects can be marketable revenue projects on a stand-alone basis. The middle section of the pyramid is most likely where a managed lanes project would fit. Often these projects are substantial undertakings that require leveraging monies from every available source and need a tremendous amount of agency cooperation to guide them through the development process. Transportation officials should make every effort to include any and all interested parties from the earliest stages of project planning, thereby fostering collaboration and helping identify potential financing sources and investment opportunities.

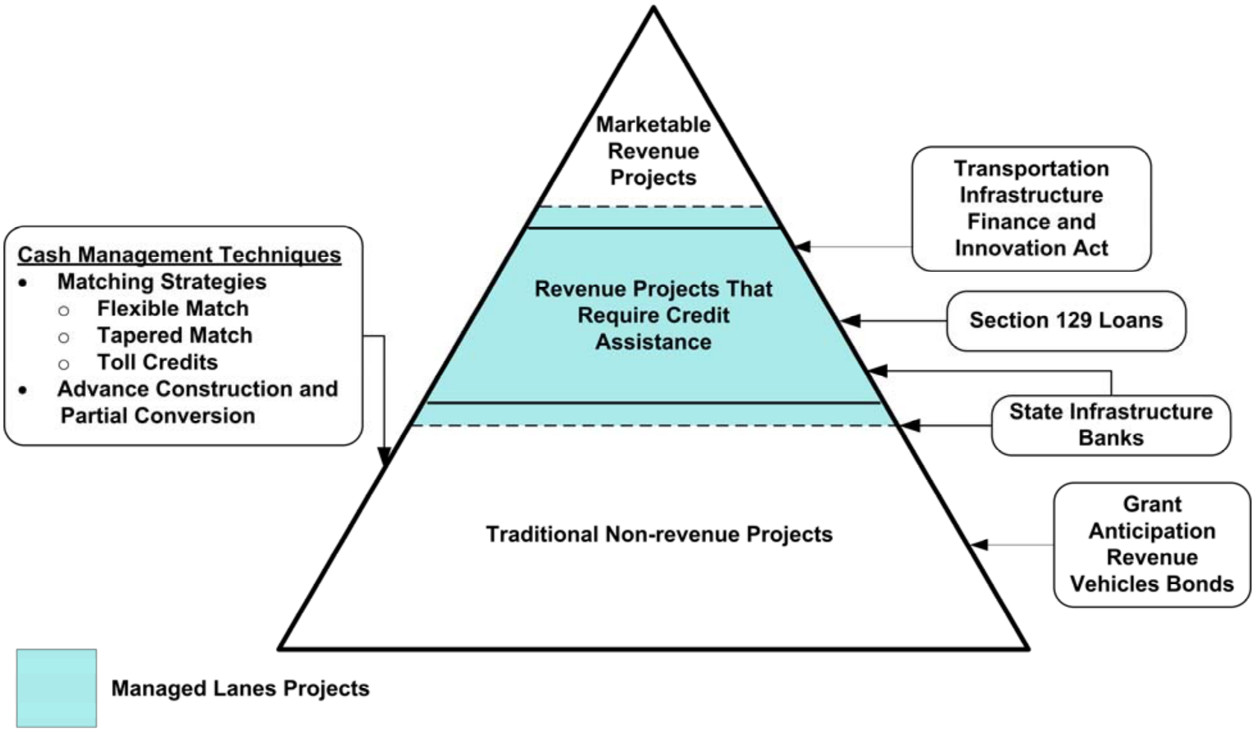

Figure 3-2. Funding and Financing Strategies (*25*).

Agencies may use all of these methods alone or in concert with one another to finance a project. Each method is designed to offer more flexibility in an effort to make projects more feasible and to get them implemented sooner. The effect of these efforts has been the ability to leverage state and federal funds.

Other new options may also be used in combination with other programs to help fund managed lanes projects. For example, a Regional Mobility Authority (RMA) is a new mechanism for implementing transportation projects in Texas. Proposed in the 2001 Texas legislative session and approved by voters, RMAs allow for more flexibility and control by local entities in developing projects that meet the needs of the region. An RMA can develop, finance, construct, operate, and maintain a transportation facility, thereby allowing projects to proceed to implementation faster than through the traditional TxDOT process. With additional legislation providing bonding and eminent domain authority, RMAs would then have the ability to issue bonds to finance projects. Typically, these projects will be toll projects and thus have a dedicated revenue stream. Financing of certain projects through an RMA will free resources for TxDOT to devote funds to other needed transportation projects that may not be financially feasible as a toll project, or as in the case of most managed lanes projects, TxDOT may leverage the available resources to enable a project to move forward by enhancing the financial viability of the project.

Public-private partnerships are another potential alternative for funding and an effective means of getting large, necessary projects implemented sooner. The ability to structure a project to obtain financing in the capital market dictates the ultimate feasibility of a project. With the creation of non-profit corporations that issue debt on behalf of the government sponsor, as the capital markets become more accustomed to highway infrastructure investment, as tax advantages are maximized, and as private sector streamlining practices are utilized, perhaps the United States will see the kinds of private investment in infrastructure that have benefited other countries.

One concept that dovetails with public-private partnerships is the notion of design-build. Though currently not statutorily allowed in Texas, the Texas Turnpike Authority (TTA) has permission to develop four projects using Exclusive Development Agreements (EDAs). These EDAs are very similar to design-build. By employing this strategy, the state hopes to shift more of the project risks to private project developers and, at the same time, make the project more financially feasible by implementing it sooner rather than later. Taking advantage of associated costs in today's dollars as opposed to future dollars attracts more private investment, bringing the project to implementation quickly and reducing overall project costs. The concept works by combining federal, state, and local investments to encourage a private developer or developers to fill the funding gap.

In addition to these potential solutions, other strategies have potential, such as:

- shadow tolls,
- special assessment districts,
- tax increment financing,
- development impact fees,
- road branding,
- utility franchise agreements,
- corporate sponsorship, or
- privatization of rest areas.

However, the legal authority does not exist in Texas to implement some of these strategies.

A successful project matches the financial package to the project goals. It is also important to explore every possible source of funding. Managed lanes that include an HOV or bus rapid transit (BRT) component are eligible for funding from the Federal Transit Administration using Section 5309 funds.

Research Recommendations

Funding and financing mechanisms available today reflect a shift from the traditional means of grant-based funding and address the realities of certain funding shortfalls. Federal and state governments, as well as state departments of transportation, are working collaboratively with other local entities and the private sector to maximize the effectiveness of every transportation improvement. Managed lanes are an innovative approach that seeks to balance the fiscal constraints of building new infrastructure, the demand for socially responsible development, and the gridlock that stifles drivers on the most congested roadways.

The key to developing a successful project is to identify the project goals and match the financing to the purpose. Managed lanes that involve a toll component typically use it as a demand management tool more so than a financing mechanism. Because managed lanes utilize various operating scenarios in a flexible way to maximize the operational efficiency of a facility, they are inherently more risky to investors. As such, tolling exclusively for financing purposes can be a challenge in a managed lane situation, depending upon other goals of the project that may be at odds with generating revenue.

Typically, investors want to have some assurances that the debt service will be paid and that rate covenants will be maintained. Therefore, the question becomes, "what is being managed?" Again, this issue relates to the goal of the project. Each of the following questions must be answered when considering the financing for a managed lanes facility:

- Is the facility being managed to increase high-occupancy vehicle usage?
- Is the facility being managed to increase transit use?
- Is the facility being managed to decrease single-occupant vehicle use?
- Is the facility being managed to provide an incentive to alternative fuel vehicles?
- Is the facility being managed to maximize revenue generation?

Additionally, the relative importance of each answer must be weighed because the project goals may seek to do all of these things and more. The answers and the weight of each will determine the best route for financing. Each facet must work together to assemble a financing package that will result in a financially feasible project. The goals of the project will determine the type of cost-benefit analysis used in assessing the potential performance of a project.

Each of the financing mechanisms described here attempts to enhance the financial feasibility of a particular project. They can be combined and structured to receive the most possible benefits in the most cost-effective manner.

The U.S. Department of Transportation (USDOT) achieved tremendous advances in making large, complex projects, such as managed lanes projects, more feasible. It has developed numerous programs to capitalize on all available resources. USDOT made leveraging federal monies more accessible. Now, however, policy makers should make a concerted effort to change or update other laws and regulations that inhibit project development. Specific items to be addressed include:

- allowing for tax-exempt financing for "public good" projects;
- limiting personal liability of board members of "63-20 corporations";
- modifying the limitations in the management contracts of tax-exempt financing;
- allowing for private equity investments in a project being developed with tax-exempt financing;
- clarifying conflicting rules among agencies on what monies can be used for which types of projects, such as Federal Transit Administration restrictions on tolling SOVs on HOV lanes; and
- passage of tax law that allows for lenders to receive tax credits rather than forcing them to rely on tax-exempt debt.

Implementation Status

Passage and signing into law of HB 3588 in the 2003 Texas legislative session broadened and enhanced the funding capabilities available to the state department of transportation and other regional transportation agencies. The scope of projects that TxDOT or an RMA may undertake has been greatly expanded. This may allow for participation in managed lanes projects that are more multimodal in nature. TxDOT benefits in the following ways:

- TxDOT now has the ability to convert free roads to toll roads under certain circumstances and the ability to use those tolls for other mobility improvements. This authority could provide needed support to a managed lanes project that is not financially self-supporting.
- The previously imposed limit on Exclusive Development Agreements has been removed, authorizing the state to enter into Comprehensive Development Agreements that allow for private sector investment in projects.
- TxDOT now has flexibility in methods to pay for rights-of-way (ROWs) that may allow them to implement projects.
- Another instrument that will aid the implementation of managed lanes projects is TxDOT's new authority to issue bonds.

Each of these tools is an effort by the state government to enhance the state's ability to provide needed transportation infrastructure. Each mechanism provides more options to the managed lanes projects under development throughout the state and may also provide the incentive to consider the feasibility of other projects as managed lanes.

MANAGED LANES RAMP AND ROADWAY DESIGN ISSUES

Because the existing experience in both design and operations of managed lanes is limited, researchers turned to work on high-occupancy vehicle lanes as a source of potential information. Criteria for HOVs have been examined in previous studies, and the findings from those studies can be applied to managed lane facilities. A previous research report, *Guidance for Planning, Operating, and Designing Managed Lane Facilities in Texas (26)*, provides guidance for the geometric design of managed lane facilities and was used to generate draft chapters for the upcoming *Managed Lane Handbook*.

Research Effort

Review of Current Literature and State-of-the-Practice for Ramp Design

Researchers conducted a literature review and a review of state manuals to determine current practices. Most of the recent literature regarding ramp design focuses on ramp design speed and truck performance. An Internet search of each state's design manual found that 23 states had all or part of their design manuals online, 12 of which had some material available concerning the design of ramps.

Case Study

The potential Texas managed lane system could contain elements of systems from other communities. Information on how these elements operate can help in the selection of components best suited for Texas. Examples include how special use lanes are signed or marked, their typical dimensions for lane and shoulder widths, and how the special use lanes are accessed. As part of this research project, members of the research team visited the New Jersey Turnpike (NJT) facility.

Computer Simulation

Simulation was used to obtain an appreciation of the effects of ramp spacing on freeway operations. A previous effort within this project focused on the impact of managed lanes access and egress weaving behavior for a single pair of ramps. Simulation of several ramp pairs is needed to identify the impact on the corridor of vehicles from different entrance ramps consistently weaving across free lanes to access a managed lane facility. The simulation performed as part of this task planned to quantify the effects of ramp spacing on freeway operations and continue the investigation of when to consider a direct ramp between the managed lanes and a generator or surface street system.

Speed was the primary measure of effectiveness used to evaluate the effects of the different ramp spacing, volume levels, and weaving percentages. Ramp spacings of 1000, 2500, 4000, and 5500 feet were used. Initial freeway volumes of 1250, 1500, 1750, and 2000 vehicles per hour per lane (veh/hr/ln) were also used. Finally, the percentage of freeway entrance ramp traffic that desired to maneuver to the next managed lanes access point was varied between 0, 10, 20, and 30 percent of the traffic on the (source) freeway entrance ramp. The 0 percent weaving scenario provided a baseline condition of how the freeway would operate without the managed lane facility.

Key Findings from the Reviews

Information on geometric design features for ramps is available in a number of sources including the American Association of State Highway and Transportation Officials (AASHTO)

A Policy on Geometric Design of Highways and Streets (27) and the Texas *Roadway Design Manual (28)*. A review of state design manuals demonstrates that the Texas manual includes more discussion and examples on ramp design than most other state manuals. An issue not well discussed in any document is where to place the ramp with respect to other entrance and exit ramps. General guidelines are provided (900 to 1000 feet, or 300 m); however, these guidelines are not sensitive to the:

- expected ramp volume,
- anticipated destination of the ramp vehicles (e.g., the next exit ramp or a downstream entrance to a managed lane facility), or
- number of lanes on the freeway.

Key Observations from the NJT Case Study

A 32-mile (52 km) segment of the Turnpike was expanded to two separate roadways in each direction of travel with each same direction roadway called a barrel, as shown in Figure 3-3.

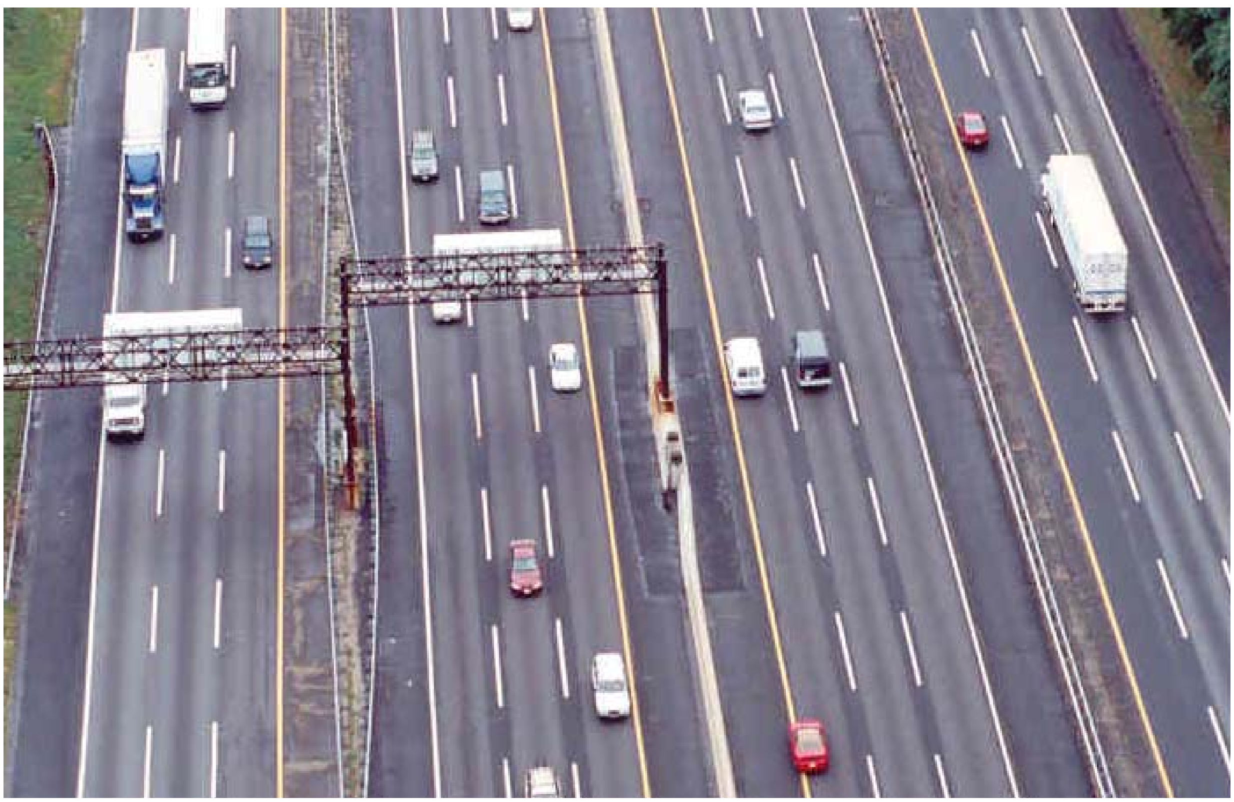

Figure 3-3. Dual-Dual Roadway of the New Jersey Turnpike.

The objective of the "dual-dual" roadway was to improve operations and safety by separating heavy vehicles from light vehicles and to increase capacity (heavy vehicles are restricted to the outer lanes). It also provides greater flexibility for using the roadway during periods of heavy congestion such as a major incident, since changeable message sign technology could be applied to warn approaching drivers and divert them to the less-congested barrel, as in Figure 3-4.

Figure 3-4. Entrance Ramp to the Dual-Dual Roadway of the New Jersey Turnpike.

Each barrel has its own exit and entrance ramps as pictured in Figure 3-5. The inner roadway traffic does not weave across the outer roadway traffic to reach an exit. The traffic from barrels in the same direction merges prior to the toll plaza. The ramp designs used at the interchanges result in having all traffic moving through one toll plaza for each interchange, as Figure 3-6 illustrates. This design allows for consolidation of personnel and equipment (and results in cost savings) in the collection of tolls. Both trumpet and slip ramp designs are employed.

Figure 3-5. New Jersey Turnpike Interchange.

Crash information available in the 2001 draft *Handbook for Planning Truck Facilities on Urban Highways* (*29*) supports the theory that the dual-dual roadway system enhances safety. During the five years before completion of the dual-dual roadway (1965-1969), the average annual accident rate was 94.1 accidents per million vehicle miles; in the succeeding five years the rate was 79.2 accidents per million vehicle miles – a reduction of over 18 percent. For the five-year period from 1994 to 1998, the crash rate on each of the outer and inner barrels was 26 to 61 percent less than on the segments of the Turnpike without separate roadways. It is still unknown how much of the difference is due to the separation of vehicles or to other factors such as fewer lanes and higher levels of congestion on the non-separated portions. The data, however, clearly indicate that accident rates are lower in the areas with the dual-dual roadways.

Figure 3-6. New Jersey Turnpike Toll Plaza.

Key Findings from the Simulation

In the simulation, ramp spacing only affected average freeway speeds when the initial freeway volumes were very high (2000 veh/hr/ln) and ramp spacing was at the lowest value used in the simulation (1000 feet) (see Figure 3-7). In each weaving level comparison, the average freeway speed dropped faster for the shorter ramp spacing (see Figure 3-8). This simulation shows that operations are more sensitive to small increases in traffic volumes when ramp spacing is shorter.

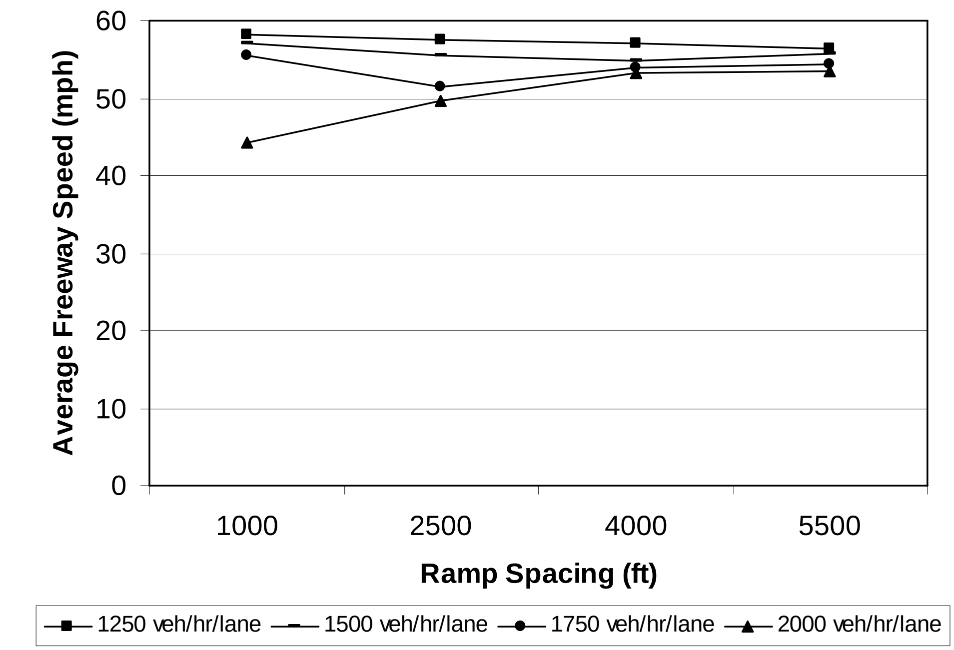

Figure 3-7. Average Freeway Speed vs. Ramp Spacing.

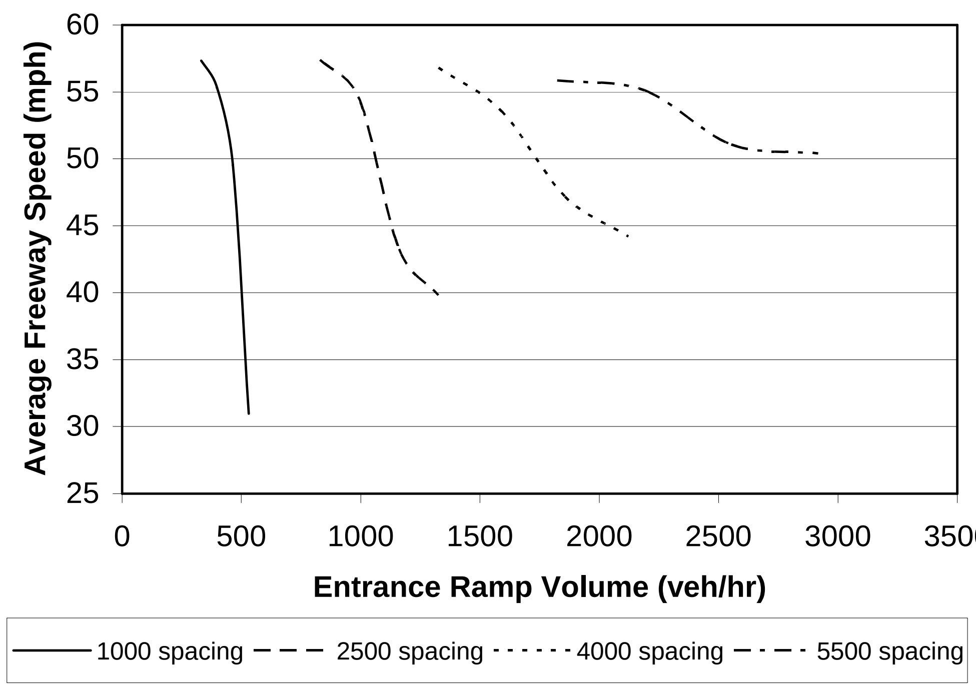

Figure 3-8. Average Freeway Speeds for 20 Percent Weaving.

The number of vehicles attempting to weave across the four freeway lanes to enter the managed lanes can have a pronounced impact on the operations of the freeway. With the exception of short spacing in combination with high initial freeway volumes, the average freeway speeds recorded from the simulation runs are generally above 45 mph until approximately 500 vehicles per hour are attempting to weave across the freeway and enter the manage lanes. When the plot of the lowest freeway speed recorded is reviewed, the point when less than desirable operations occur is at approximately 250 veh/hr (see Figure 3-9).

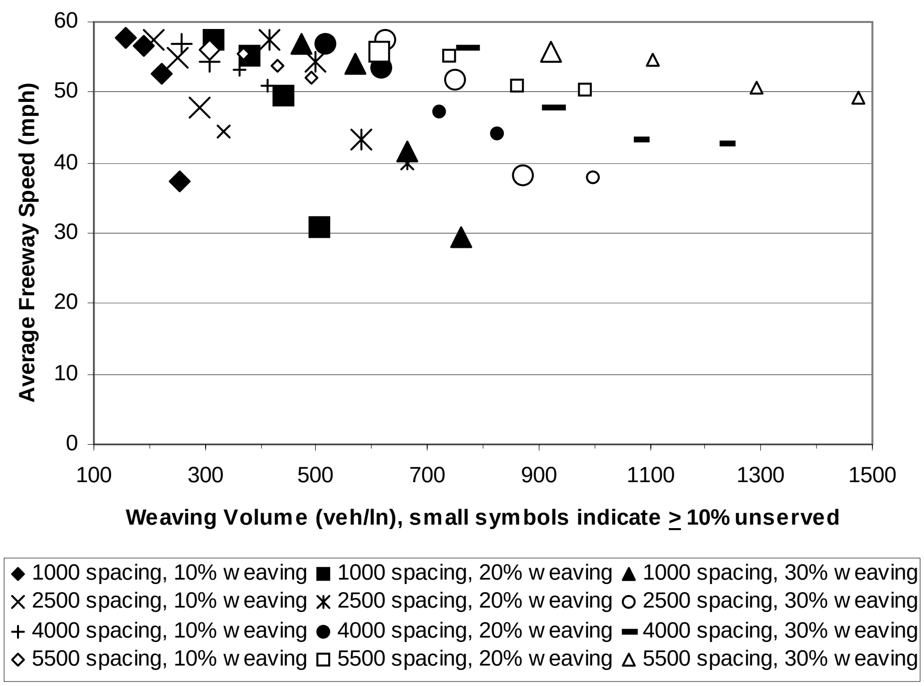

Figure 3-9. Freeway Speed vs. Weaving Volume.

Research Recommendations

The dual-dual portion of the New Jersey Turnpike clearly demonstrates the operational and safety benefits of separating vehicle modes. Having the entrance to an HOV or passenger-car exclusive facility located in the center of a freeway corridor without a dedicated ramp requires vehicles to weave across each of the general purpose (GP) lanes. The direct access to each barrel provided on the New Jersey Turnpike eliminates this weaving maneuver (which promotes a safer and more operationally efficient system). Maintaining similar geometric criteria for both barrels also provides greater flexibility in moving traffic between the barrels as needed for incidents and maintenance. In addition, the finding that the dual-dual portion has a lower crash rate supports separating trucks and passenger cars. The *High-Occupancy Vehicle Facilities: A Planning, Design, and Operations Manual* *(30)* indicates that a direct connect ramp should be considered when ramp volume is 400 veh/hr. The findings from the simulation performed as a part of this TxDOT project support that number. When considering average speeds, the number is about 500 veh/hr for the freeway traffic and about 300 veh/hr for the entrance weaving traffic. Using this simulation, a value of 400 veh/hr could be a reflection of a rounded value that gives consideration for both average freeway speeds and average entrance vehicle speeds. If the preference is to consider lowest speeds observed (a more conservative situation), then a direct connect ramp should be considered at 275 veh/hr. Report 0-4160-10: *Managed Lane Ramp and Roadway Design Issues* *(31)* contains the complete results of this research task.

ENFORCEMENT PROCEDURES AND DESIGN

A managed lanes facility requires effective enforcement policies and programs to operate successfully. Transportation agencies employ strategies to regulate demand, and those actions require enforcement to maintain the integrity of the facility. Enforcement of vehicle-occupancy requirements, use by authorized vehicles, or proper toll collection is critical to protecting eligible vehicles' travel time savings and safety. Visible and effective enforcement promotes fairness and maintains the integrity of the managed lane facility to help gain acceptance among users and non-users.

Development of enforcement policies and programs ensures that all appropriate agencies are involved in the process and have a common understanding of a project and the need for enforcement. Participation by the following parties is critical for enforcement agencies:

- the courts and legal system,
- state departments of transportation, and
- transit agencies.

This process begins by applying the appropriate enforcement strategy.

Research Effort

The purpose of the enforcement task was to outline enforcement procedures and design elements of managed lanes. These procedures vary depending on user groups, operational parameters, and application of available technologies. The research results provided an overview of enforcement issues for operating freeways with managed lanes and explored the role of enforcement through identifying the available enforcement strategies and elements of enforcement area design.

The state-of-the-practice for managed lanes enforcement at various locations around the country gives insight into items to consider when developing an effective enforcement program. Lastly, this task acknowledges that managed lanes enforcement is becoming ever more dependent on technological advancements in presenting innovations in the area of automated enforcement technology, specifically:

- automated vehicle identification (AVI),
- license plate recognition (LPR), and
- electronic toll collection (ETC).

Key Findings

Enforcement procedures and design elements of managed lanes vary depending on user groups, operational parameters, and application of available technologies. The enforcement strategy chosen for managed lanes is usually one of the following:

- routine enforcement,
- special enforcement,
- selected enforcement, or
- self-enforcement.

Routine enforcement uses existing freeway patrols to monitor managed lanes, while special enforcement uses dedicated equipment and manpower specifically to monitor the managed lanes. Selective enforcement is a combination of the two strategies and may be used for specific events or concerns, such as the opening of a new managed lane facility or to combat high violation rates. The last enforcement strategy relies on the concept of self-enforcement. This strategy involves promoting citizen monitoring and self-regulation by users of the managed lane and the motorists in adjacent general purpose lanes.

Traditional enforcement on managed lanes often requires dedicated enforcement areas, which are usually located immediately adjacent to the managed lane facility and allow enforcement personnel to:

- monitor the facility,
- pursue violators, and
- apprehend violators to issue appropriate citations.

However, recent advances in automated enforcement technology may lower the number of dedicated enforcement areas needed in the future, thereby shifting the focus of design to proper placement of electronic equipment. Enforcement areas can also be classified as either low speed or high speed and usually by type of separation from the general purpose lanes. Low-speed enforcement areas are associated with facilities that offer some sort of barrier separation and are usually located near entrance or exit ramps. High-speed enforcement areas are associated with non-barrier-separated or buffer-separated facilities, either concurrent flow or contraflow, and are located along the managed lane mainline.

Busways, managed lanes on separate rights-of-way, and barrier-separated freeway projects usually locate low-speed enforcement areas at access points. Specific locations may include ramps, reversible lane entrances, and queue bypasses where vehicle speeds are relatively slow, usually below 45 mph (75 kph). In the case of reversible-exclusive managed lane facilities, the geometric requirements for reversing a facility provide temporary enforcement areas within the ramp areas that serve the opposing peak-period direction.

Planners design areas to provide for monitoring, apprehension, citing of violators, and, where practicable, violator removal from the managed lane facility. The design feature of barrier separation acts as a deterrent to potential misuse, as barriers confine violators in the lanes once they make the decision to enter the facility.

The following design features may be considered with low-speed enforcement areas:

- The enforcement area should be at least 100 feet (30 m) in length and preferably up to 200 feet (60 m) on high-volume facilities, not including approach and departure tapers.
- The enforcement area should be at least a width of 14 to 15 feet (4.3 to 4.6 m).
- The enforcement area should have an approach taper of 2:1 or 30 feet (9.1 m).

- The enforcement area should have a departure taper of 10:1 or 150 feet (45.7 m) to allow for vehicle acceleration into the lane.

High-speed enforcement area design usually involves spacing multiple areas periodically along facilities that have multiple at-grade access locations or that lack continuous shoulders wide enough for enforcement. Transportation agencies usually design these areas for monitoring traffic and apprehending violators. Most apprehension activities occur at a downstream enforcement area or location with a wide left or right shoulder. The following design features may be considered with high-speed enforcement areas:

- The length of a high-speed monitoring area should be at least 100 feet (30 m), not including the approach and departure tapers. For monitoring and apprehension, the preferable length is 1300 feet (396 m).
- The enforcement area should be at least 14 to 15 feet (4.3 to 4.6 m) in width.
- The enforcement area should have an approach taper of 115:1 and a departure taper of 80:1 or higher, or it may be controlled by general freeway criteria as required to fit in the design for proper acceleration to the design speed.
- Enforcement areas should be provided at a minimum interval of 2 to 3 miles (3.2 to 4.8 km) along the mainline managed lane facility.

Enforcement of two-way and reversible barrier-separated managed lane facilities is considered easier than enforcement of buffer-separated lanes due to limited access points. Violators may be stopped at entry and exit points where travel speeds are usually lower. A reversible facility allows enforcement personnel to monitor the facility from ramps that are not in use due to managed lane traffic moving in the opposing direction.

Non-barrier managed lanes are the most difficult to enforce due to motorists' ability to enter and exit the lane at any time with relative ease. The maneuver is as simple as moving from one lane to another. Therefore, routine and consistent enforcement, whether perceived or seen by the public, is critical to managing lane violations. Figure 3-10 provides examples of cross sections and layouts for different types of enforcement techniques used with buffer-separated managed lanes.

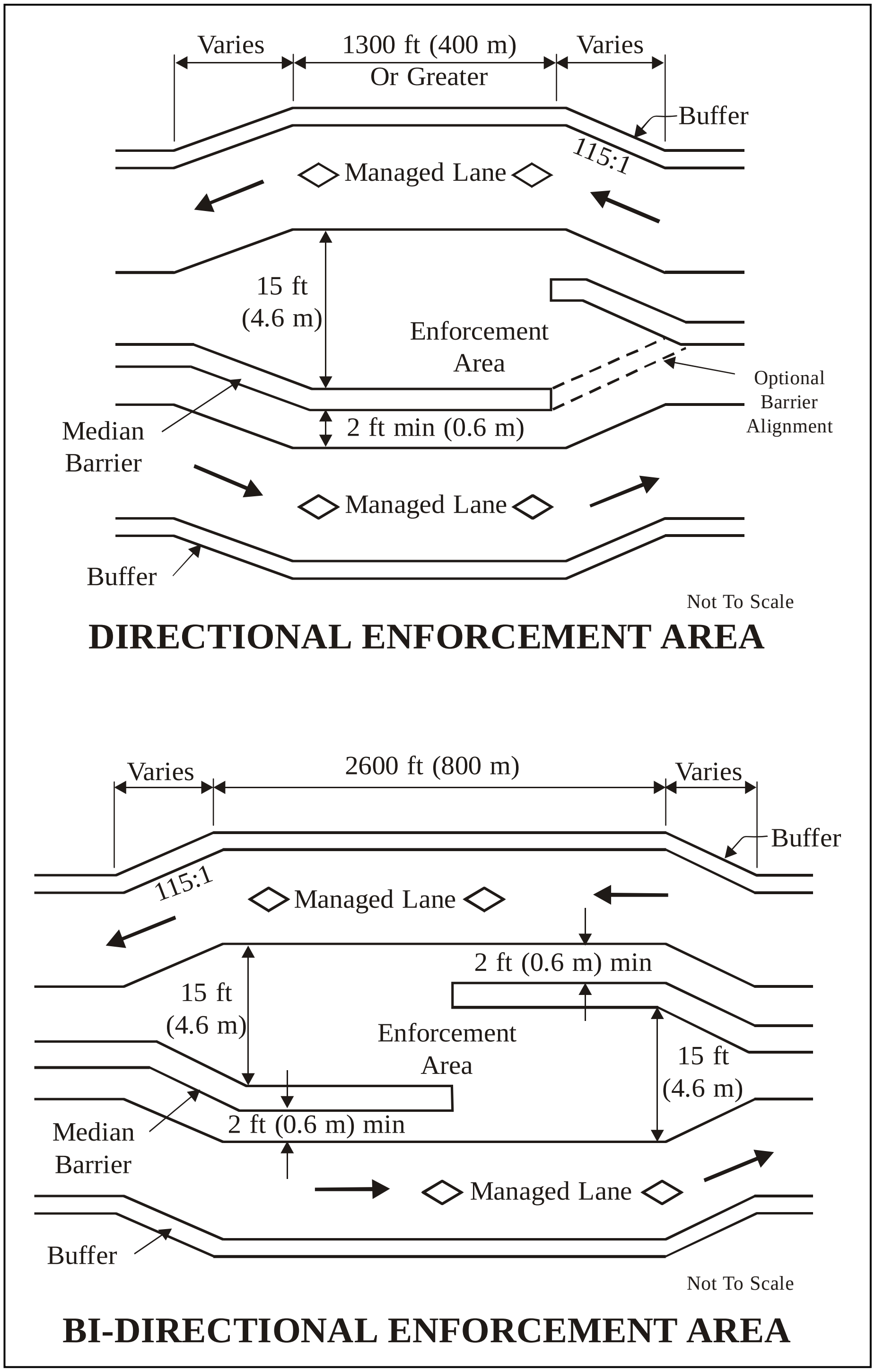

Figure 3-10. Examples of Directional and Bi-directional Enforcement Area Layouts (*32*).

Development of effective managed lane enforcement practices and procedures requires an understanding of existing managed lane enforcement programs and the responsible agencies. Examples of successful managed lane enforcement programs can be found in Orange County and

San Diego County in California and in the Texas cities of Houston and Dallas. The “HERO” program of self-enforcement was first developed in Seattle, Washington, and has been successful as a public relations tool. The city of Minneapolis, Minnesota, is an example of an area that has had less than desirable results regarding its HOV lane enforcement program because of excessive onlooker delay from enforcement activities. An HOV lane enforcement program in the city of Toronto, Canada, offers a glimpse of the future of managed lane enforcement through the use of technology.

In California, the California Highway Patrol (CHP) has contracted their services for focused managed lanes enforcement on the SR-91 Express Lanes in Orange County and the IH-15 Express Lanes in San Diego County. Prior to the CHP agreements, enforcement activities focused primarily on issues of safety and other enforcement responsibilities with managed lanes enforcement being secondary. A noticeable reduction in managed lane violations has been attributed to the dedicated CHP enforcement of these two facilities.

The transition to technology-based enforcement is evident on the IH-15 Express Lanes in San Diego County, California, and the IH-10 (Katy Freeway) and US 290 (Northwest Freeway) in Houston, Texas. California uses electronic monitoring equipment to determine whether a solo motorist has paid the required toll to use the facility usually reserved for transponder-equipped vehicles with two or more occupants. A similar buy-in program, known as QuickRide, is available in Houston that allows vehicles with two occupants to use the facility during time periods reserved for vehicles with three plus occupants.

Metropolitan Transit Authority of Houston (Houston METRO) police officers provide enforcement on Houston area HOV lanes. At least one METRO police officer is present in the HOV lane corridor during the hours of operation. Officers take enforcement action at specified enforcement areas that do not interfere with the flow of traffic.

The opening of the Highway 407 express toll route (ETR) has credited Toronto, Canada, as a world leader in the field of electronic tolling and enforcement. The most unusual feature of this facility is the ability to collect tolls from transponder-equipped vehicles or those with automated vehicle identification systems, as well as cash customers, without using toll plazas. A license plate recognition system is able to identify about 80 percent of vehicles not equipped with transponders. People view digital images of the other 20 percent in an effort to identify vehicles for billing.

Research Recommendations

Successful enforcement of managed lanes requires appropriate application of available resources. Enforcement strategies vary depending on the amount of enforcement required to ensure that the rules and regulations of managed lanes are maintained, ranging from continuous enforcement to the simpler process of self-enforcement. A review of the various HOV enforcement practices across the country indicates that there are multiple variations for the enforcement of managed lanes with varying levels of success.

Barrier-separated facilities obviously experience less violation than buffer-separated facilities due to the more restrictive nature of the design. The level of importance that responsible enforcement agencies place on managed lane facilities also dictates the restrictive nature of the facility. The enforcement practices at the operational managed lane facilities from around the country indicate the level of commitment to enforcement of several of the agencies. The most notable of these agencies is the California Highway Patrol that has been contracted for the specific purpose of monitoring the SR-91 Express Lanes in Orange County and the IH-15 Express Lanes in San Diego County.

This task also focused on the concurrent flow and barrier-separated, reversible HOV lanes in Minneapolis, Minnesota. Underutilization and excessive occupancy violations characterize HOV lane operation on both IH-35W and IH-394 because of limited enforcement. Previous attempts to enforce these facilities resulted in severe congestion on the general purpose lanes due to onlooker delay. Perhaps other enforcement techniques are in order that do not interrupt the flow of traffic. This is the case with automated enforcement technology.

The use of automated enforcement technology is growing at an ever-increasing rate. This project acknowledges the use of automated vehicle identification, license plate recognition, and electronic toll collection as the ways of the future concerning enforcement of managed lanes. Report 0-4160-11: *Enforcement Issues on Managed Lanes* *(33)* contains the complete results of this research task.

IDENTIFYING TRAVELER INFORMATION AND DECISION-MAKING NEEDS

An implied goal of the managed lane concept is to offer additional choices to motorists on a section of freeway. These choices can vary by time of day or possibly in response to changing traffic conditions on either the managed lane or the other general purpose lanes in the corridor or region. The extent to which travelers can and will accommodate such operational flexibility hinges on getting the right information to travelers, at the right time and in the right format so that they can make effective decisions pertaining to their trip.

Some users of managed lanes make decisions prior to the start of their trip. However, others may make such decisions en route to their destination. The information needed to support such decisions must be safely and effectively interwoven with that information required for motorists to safely control, guide, and navigate their vehicles into and along the managed lanes. To further complicate matters, this information must often be presented next to adjacent general purpose lanes. Obviously, in such a complex information environment the potential for information conflicts and overload exists.

Research Effort

This task involved researching managed lanes traveler information and decision-making needs for managed lanes users. The research provided an overview of previous literature and available analysis tools relevant to traveler information overload and positive guidance in a freeway and/or managed lane environment. It also contained the results of a series of focus groups to investigate motorists' understanding of several managed lane operational issues and information concepts. Finally, it contained a critical analysis to assess information needs that support key decisions by motorists attempting to use various types of managed lanes.

Key Findings

Given the limits of human information processing, efforts to design facilities and information systems to be consistent with drivers' expectancies should result in:

- minimizing their overall driving workload,
- minimizing errors, and
- maximizing the consistency of the resulting driving behaviors.

By considering the information needs earlier in the design process (prior to exit ramp and managed lane entrance location selection, for example) transportation agencies can more easily address the information needs of drivers.

Research Recommendations

Researchers developed a conceptualized decision model (see Figure 3-11). This model incorporates the information a driver needs to correctly answer each of the questions required in the process of deciding whether a managed lane facility is a better choice than the general purpose lanes. The model also takes into account not only the specifics of the managed lane facility and traffic conditions, but also the qualitative specifics of the individual driver. Although the assessment alludes to a benefit-cost analysis, it is not performed with numbers and mathematics. Rather, drivers process this information in their minds in real time or just prior to the trip, and the thoughts may be more of a perceptual assessment than a precise computation.

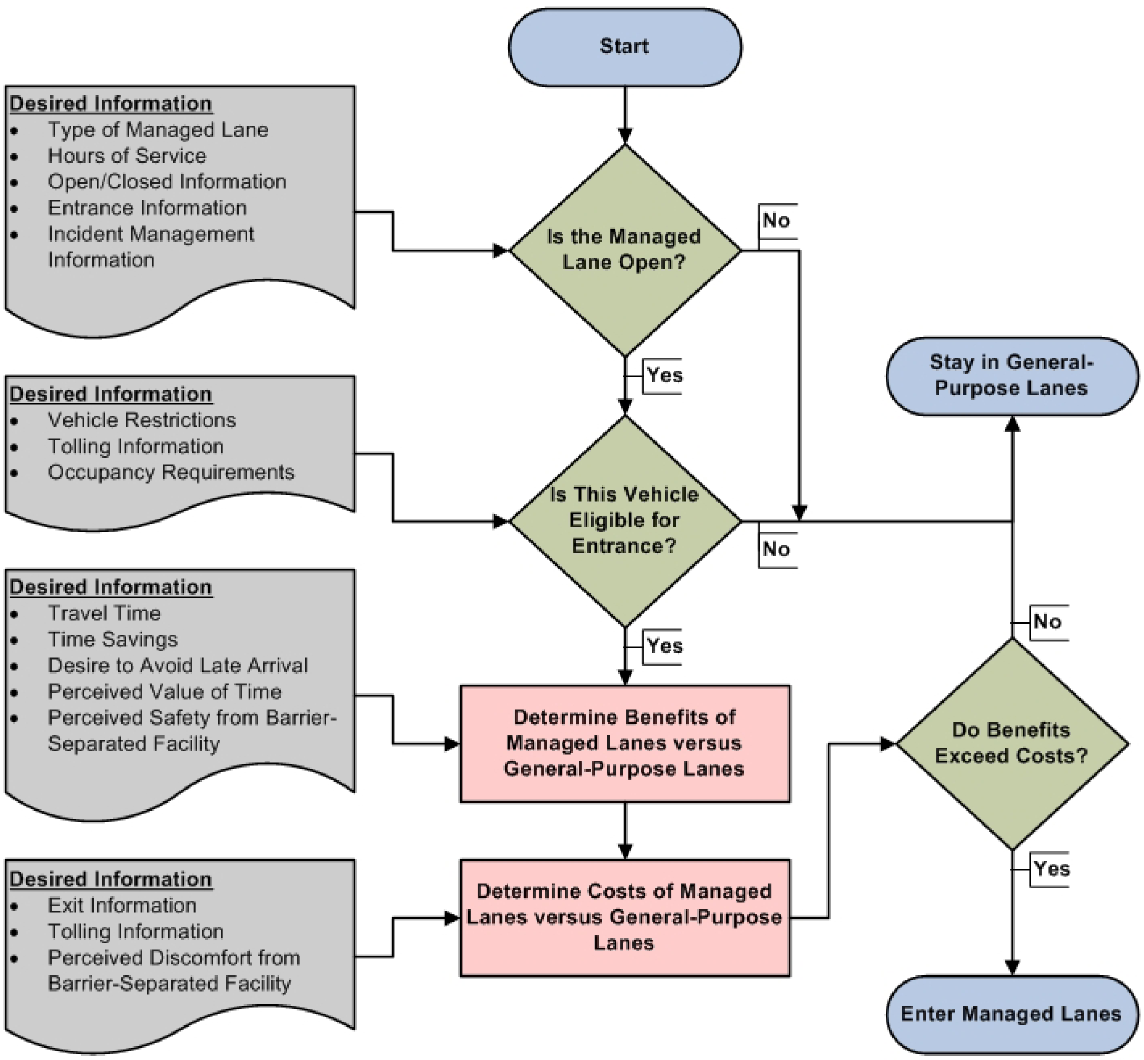

Figure 3-11. Conceptualized Traveler Decision Model.

One of the more important considerations for facility designers is that managed lane information needs are also highly dependent upon traveler experience and other individual factors. Certainly, not all of the information needed to make an informed decision must come from the highway agency in terms of information dissemination devices, such as:

- overhead and shoulder-mounted static signs,
- overhead and shoulder-mounted dynamic message signs, and/or
- pavement markings, etc.

Some of the information required is internal to each individual driver, such as the perceived value of time and the level of comfort with entering a barrier-separated facility. Drivers can learn other information, such as geometric features or specific sign locations and content, over time through repeated trips through a corridor. Drivers experienced with a particular roadway would also be likely to have some expectations of typical traffic conditions during their trips, including speed and congestion at different times of day as well as areas where additional attentional demand is required such as at interchanges with weave areas. Drivers who have been through a specific corridor before could likely be considered to need to acquire less information and rely more heavily on information stored in the driver's mind.

A general classification of drivers who might reasonably be confronted with the decision of whether or not to enter a managed lane includes the unfamiliar driver, the semi-familiar driver, and the very familiar driver. The entire driving population would fill the continuum between the extremes of a completely unfamiliar driver and a completely familiar driver. Figure 3-12 illustrates the concept that familiarity with managed lanes facilities reduces the amount of information needed by the driver during a trip.

Other Information Sources

There are limits to human information processing. It is possible in some driving instances to provide so much information that some drivers are not able to process it all. Additionally, since many types of managed lane driver information are complicated and must come in addition to general purpose lanes information, drivers with lower information processing capabilities will be hard-pressed to correctly read and process the information provided.

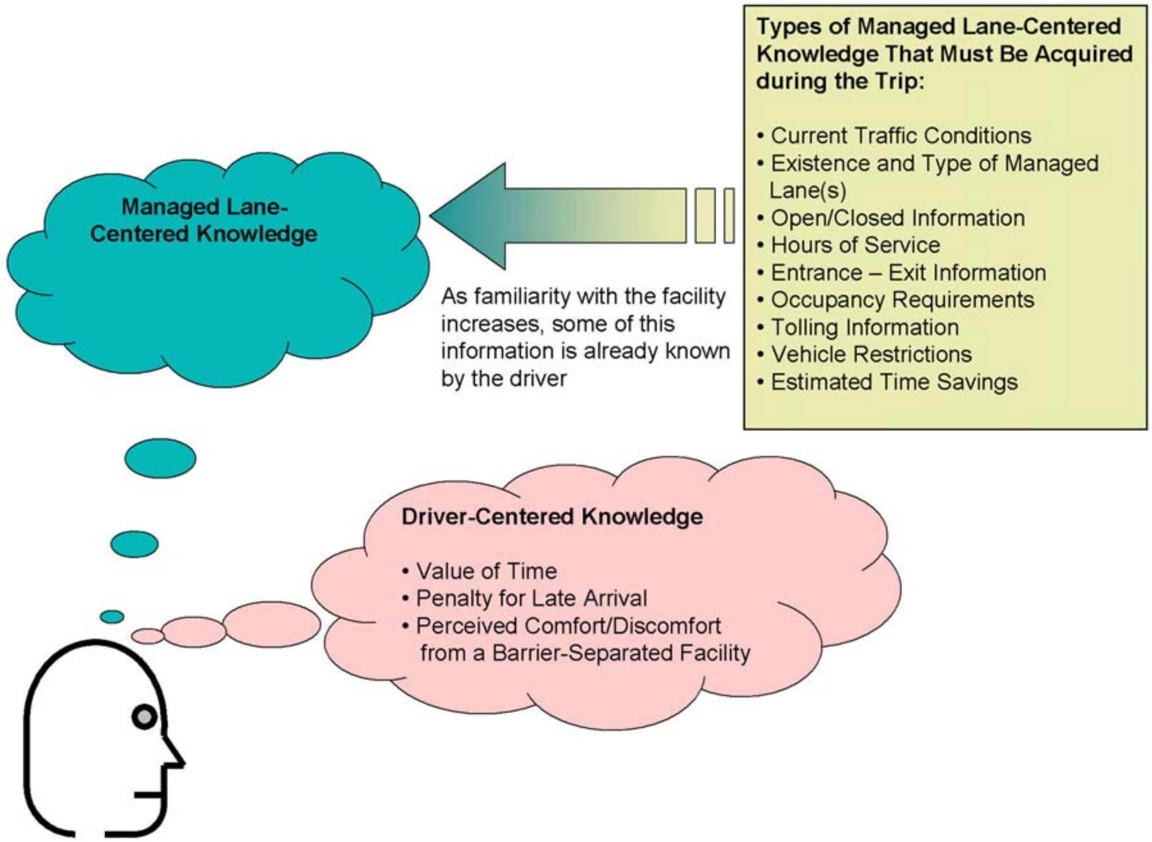

Figure 3-12. Driver Information Needs.

If general purpose and managed lane information is presented on the same overhead guide sign or on separate sign structures but is still readable at a single point, conflicts in exit or distance information may occur. A review of the information may reveal that some of the information can safely be shifted upstream or downstream to spread the information load.

Determination of who the target audience really is (familiar, semi-familiar, or unfamiliar drivers) can help determine how much information must be presented within the managed lane corridor regarding the managed lane. This step needs to happen early in the design process so the designers can make rational decisions about what levels of information they need to present. Additionally, if the target audience can be defined specifically, such as toll users who have electronic transponders, other options for information dissemination become available. Defining the target audience is a process that should be explicitly determined in the design process, as it directly relates to the dissemination alternatives available for certain kinds of information.

Examples of possible information that transportation agencies could remove from signs and put into mailings include:

- hours of service,
- toll structure,
- average time savings, and
- planned uses for the managed lane facility.

In this manner the information acquisition activity would move from during the trip to prior to the trip. Internet information pages can also serve a similar purpose for unfamiliar drivers who desire to learn more during pre-trip planning. The researchers documented the results of this task in Report 0-4160-13, *Identification of Traveler Information and Decision-Making Needs for Managed Lanes Users* (*34*).

DEVELOPING RECOMMENDATIONS FOR TRAFFIC CONTROL DEVICES FOR MANAGED LANES

Managed lanes facilities may present drivers with unfamiliar access, geometries, and operating rules. Conveying information concerning these features requires effective use of standard and novel traffic control devices. As managed lanes facilities continue to evolve, new operational strategies and geometric designs may require new traffic control devices.

Designers and operators of managed lanes facilities must consider traffic control device needs early in the planning process. Beyond the initial and ongoing costs of traffic control, early consideration of driver information needs in the planning process assures that an operating scheme is not implemented that requires overly complex signs. For example, variable tolls based on occupancy or time of day with dynamic pricing based on current conditions can result in complex toll schedules.

In addition to operating strategies, planners need to consider traffic control devices in the geometric design as well. Access points that violate driver expectancy, such as left exits, will require good advanced signing. Buffer-separated facilities pose a particular problem because there is often insufficient clearance in the median for adequately sized signs.

Research Effort

The research team conducted a thorough review of U.S. standards for:

- traffic control devices for managed lanes,
- high-occupancy vehicle lanes,
- special use lanes, and
- toll facilities.

This review included a summary of current practices in the United States and other countries and highlighted differences between current practice and new standards. Careful sign placement and color coding were also investigated as alternative ways to avoid driver information overload. Finally, using the technical review and input from focus groups across Texas, the researchers provided numerous recommendations regarding good sign practices for providing managed lanes information to travelers within the roadway environment.

Key Findings

Current managed lanes facilities, including HOV lanes and toll facilities, use a variety of traffic control devices. This is, in part, due to the lack of guidance and standardization in the *Manual of Uniform Traffic Control Devices (MUTCD)*. Also, the course of development for many of these facilities leads planners to feel that theirs is a "one of a kind" facility where standard signs do not apply. While, for the most part, existing signing has been developed with guidance and in the spirit of the *MUTCD*, there is little consistency currently in this area.

The current *MUTCD* contains eight pages of example layouts for both barrier- and buffer-separated facilities (Section 2E. 59) (*35*). These examples illustrate:

- green advanced guide signs,
- exit plaques,
- distance/destination signs with a small diamond symbol in the upper left corner,
- special lane drop symbol warning signs,
- trailblazer signs from park-and-ride facilities,
- local streets, and
- direct access ramp diagrammatic guide signs.

Guidance is provided to avoid overloading the road users. The *MUTCD* suggests the importance of signs following this priority:

- regulatory,
- advance regulatory,
- guide, and
- next exit supplemental signs.

Several “shall” conditions have been added to the *MUTCD* concerning preferential lanes that merit individual mention (see Section 2E.59) (*35*). These conditions include:

- a minimum of one ground-mounted advance guide sign at least 0.5 mi (800 m) prior to the entry;
- overhead signs for use as a supplement to ground-mounted signs only, unless an engineering study identifies that ground-mounted signs are not appropriate;
- HOV abbreviation or diamond symbol to appear on all signs at entry and exit points and times of vehicle occupancy requirements; and
- median-mounted signs for advance exit and other guide signs for both barrier- and buffer-separated facilities (allows twisting of sign up to 45 degrees where lateral clearance is limited).

The new *MUTCD* also addresses warning signs and pavement markings. Section 2C.52 allows for the option of augmenting a warning sign with a small yellow plaque that reads “HOV.” This plaque “may be used to differentiate a warning sign specific for HOV lanes when the sign is also visible to traffic on the adjoining general purpose roadway.” The *MUTCD* suggests using this plaque for advisory speeds for curves and exits, lane adds, and lane drops. Some agencies, in practice, have added either “HOV” or the diamond symbol to warning signs.

The *MUTCD* has more comprehensive coverage of pavement markings for preferential lanes as well. Sections 3B.22 and 3B.23 provide specific guidance on longitudinal pavement markings and symbols for all types of preferential lanes. A clear table, with illustrations, is provided for edgeline markings for buffer- and barrier-separated facilities with both concurrent and reversible operations. These improvements will help develop standardization among future facilities and as existing facilities are upgraded and maintained.

Research Needs – Color Coding

The research team recommends the adoption of uniform symbols for electronic toll collection and uniform colors for these applications. Toll roads have been an area where sign agencies have been more willing to utilize banners, logos, and unique colors throughout their traffic control devices. Technically, toll roads are obligated to conform to the *MUTCD* since the document applies to all roads open to travel by the public. Toll road operators, however, have sought ways to "brand" their roads. While some in the transportation engineering community scoff at this branding as using traffic signs as advertisements, the use of a consistent and unique symbol or color may benefit travelers in navigating.

Research Needs – Symbols and Terminology

The following sections highlight future research needs related to symbols and terminology that will enhance the research results presented herein.

Allowed Vehicle Symbols

The use of symbols to indicate allowed vehicles is non-standard but used frequently. A consistent symbol set for buses, motorcycles, and ILEVs needs to be developed. In addition, occupancy symbols for carpools should be standardized. No visibility or comprehension research has been found on any of the symbols in use today. From a sign design perspective, symbols are preferred because they occupy less space and can be used in a modular fashion whereby the overall footprint of the symbol is a standard size. In addition, for areas with non-English speaking drivers, symbols may be preferred. Research and design work are needed on these symbols to assure good legibility and comprehension. A symbol for ILEVs could be particularly difficult to develop.

For subscription-based programs that allow registered vehicles to pay a toll to be exempt from occupancy requirements, such as the QuickRide program in Houston, a symbol could be used to identify to subscribers when they are allowed in the lane. Symbols may also be desirable to indicate forms of payment accepted or excluded. These symbols may be similar or identical to icons or logos used for electronic payment systems and in other marketing materials. The consistency in message gained by repeated use of these types of symbols will lessen the information processing load of regular road users, but may cause confusion to unfamiliar users who may have trouble comprehending novel symbols.

The use of symbols may also be extended to signs indicating excluded vehicles. The use of the red circle slash may need to be avoided on vehicle symbols because of the fine detail present in these icons that the prohibition marking could obscure.

Access Point Terminology

Focus groups conducted as part of this overall project indicated that the vast majority of drivers thought of the access area as "entering" the managed lane, not "exiting" the general purpose lane. Yet, all signs in the manual indicate the movement from the general purpose lane to the managed lane with an EXIT sign. Clearly, there is a disconnect between the average driver's conceptualization of the roadway network and the signing practices in this area. Likewise, signing for the parallel general purpose lanes with the use of route shields may confuse drivers accessing the managed lanes, because in their minds the managed lanes are the identical route number or name as the general purpose lanes.

These issues are particularly relevant to signing for facilities with parallel managed lanes. More research is needed that surveys average drivers as to their inherent understanding of routes and other global navigational issues so that the signing system can support the driver's natural understanding.

Allowable Exits

One impediment to HOV lane use cited in the focus groups was that drivers were uncertain as to where they would be able to exit from the system, particularly for barrier-separated facilities. Focus group participants expressed a desire and expectation to be notified at least of the next exit point and preferably if a major interchange was not accessible from the managed lane.

The new *MUTCD* does illustrate some advance exit signing in Figure 2E-46 that places exit names and distances on green guide signs mounted on the left side of the road. These exits and distances are intended for the managed lane users only. Caution needs to be exercised in sign design and placement to avoid presenting managed lane exit information that conflicts with the general purpose lanes.

Supplemental Information

Information related to electronic toll tag subscriptions, transit information, carpool registries, and other programs is often presented along a roadway. This is even truer for managed lanes due to their restrictive nature and the possible revenue enhancement from promoting these programs. The *MUTCD* currently prohibits the placement of Internet addresses on traffic control devices. As Internet usage nears universality, the use of web addresses may be preferred to telephone numbers for these applications. Web addresses can be selected that are easier to remember than telephone numbers, thus lessening the information load on drivers.

Supplemental information should always come second to the necessary warning, guidance, and regulatory functions of traffic control devices. Care must be exercised in placing supplemental information to avoid installing signs near decision points or where they may direct attention away from necessary maneuvers.

Sign Placement

Sign placement is a difficult issue for managed lanes facilities. The *MUTCD* provides somewhat confusing information as to when to place signs overhead, on the right shoulder, or on the left-side median barrier. Particularly for concurrent flow facilities with limited access areas, conflicting information regarding distances to exit points for the managed lanes and general purpose lanes may exist. In these situations, it is critical to identify the information for the managed lanes by careful placement. Separate cantilevers rather than full-span sign structures are preferred. If separate cantilevers are not possible, managed lanes signs should be as far left as possible, preferably with a noticeable gap between them and signs for the general purpose lanes.

Placing signs on the left median is desirable, but lateral clearance restrictions may prevent this application in many instances. On multiple-lane managed lanes, left-side placement may not be the best solution as larger vehicles in the inside lane may block the left-mounted signs from vehicles in the outside managed lane.

Changeable Message Signs

Changeable message signs can be an important instrument to display traffic alerts, construction updates, and other real-time information. Existing guidelines concerning message construction and message phasing should be followed for managed lanes applications. Agencies may wish to consider placing a static plaque identifying the applicable lane above changeable message signs if the information in the sign applies only to the managed lanes.

Information overload may occur if complex operating schedules and variable pricing based on vehicle class and occupancy are conveyed through multiple phase changeable message signs. Other communication means, such as highway advisory radio or mailings to subscribers, should be considered to convey this information.

Pavement Markings

The use of the diamond symbol in special use lanes is encouraged to discourage violators. Other horizontal signing applications such as speed limits or route numbers may also be beneficial. The *MUTCD* section on longitudinal markings makes specific recommendations for a variety of managed lane facilities but does not cover all possibilities. There has been little research on driver understanding of the use of broken white lines where crossing is permitted. Some focus group participants did indicate an understanding of the prohibitive nature of double white lines and the permissive nature of broken white lines. Many respondents, however, were not aware of these meanings.

The researchers documented the results of this task in Report 0-4160-16: *Traffic Control Devices for Managed Lanes (36)*.

DEVELOPING A FRAMEWORK FOR OPTIMUM INCIDENT MANAGEMENT

Much has been documented regarding traffic incident management for general purpose lanes on controlled-access highways. Incident management for general purpose lanes and that for managed lanes share many of the same goals; consequently, many of the techniques, policies, and procedures are the same for facilities of both categories.

In the context of this research, "managed lanes" can include any type of lane that maintains free-flow travel speeds on designated lanes or facilities by providing managed access to participating groups of vehicles. Examples could include any of various combinations of the following:

- express lanes,
- HOV lanes,
- HOT lanes,
- exclusive lanes,
- bus lanes, and
- lane restrictions.

Among the various principles for incident management for general purpose facilities, perhaps the most important is the development, and maintenance, of relationships among key individuals from each of the involved agencies. While it may not be uncommon for the heads of agencies (e.g., local and state law enforcement, local and state transportation departments, transit agency, etc.) to meet periodically during the normal course of events, this type of interaction cannot take the place of familiarity and healthy working relationships among operations staff members from these and other critical agencies.

In addition to working relationships, another characteristic of successful incident management programs is the use of various types of agreements, including mutual-aid agreements, hold-harmless agreements, wreckage clearance policies, etc. These agreements and various other elements of incident management programs are common to successfully minimizing non-recurring congestion due to freeway incidents in general purpose lanes. These elements are also common to incident management programs for managed lane facilities. In addition to these incident management elements, the unique features of various types of managed lanes introduce additional aspects to incident management.

Research Effort

The purpose of this task was to identify incident management policies and procedures that are critical to facilities with managed lanes and provide agencies with recommendations on best practices. To gather information from managed lanes operators and other interested parties from around the nation, the research team developed an incident management survey and disseminated it online.

The task team assembled an advisory committee of personnel from TxDOT, Harris County Toll Road Authority (HCTRA), METRO, North Texas Toll Authority (NTTA), and Dallas Area Rapid Transit (DART). The committee provided input on the development of the survey instrument and commentary on the findings from the survey recipients' responses.

In addition to conducting a thorough literature review, the research team conducted an incident management survey that was distributed to an online national audience, including individuals who serve on incident management committees and task forces in numerous locales and with multiple professional associations. This group includes representatives from:

- state and local departments of transportation,
- state and local law enforcement,
- fire and emergency medical services departments,
- transit agencies,

- towing firms, and
- other entities involved in incident management.

The survey was structured such that the respondent could provide input for each type of managed lane, including:

- express lanes,
- high-occupancy vehicle lanes,
- toll lanes,
- high-occupancy toll lanes,
- truck lanes,
- truck-restricted lanes,
- transit lanes, and
- others.

The survey included the following sections:

- general information on managed lanes facilities,
- incident management for managed lanes,
- emergency vehicle use of managed lanes for incidents in GP lanes,
- GP incident diversion into managed lanes,
- questions for agencies without plans for diverting GP traffic into managed lanes during GP incidents, and
- final comments.

The receipt of the survey results was followed by some limited telephone interviews from selected incident response team members for clarification of their responses to survey questions that required narratives.

Key Findings

Many incident management tools for general purpose lanes apply to incidents in managed lanes as well. Among these are the use of intelligent transportation system (ITS) incident detection and verification technologies; the use of dynamic message signs, highway advisory radio, and other means of motorist communication; team building and relationships among multiple agency personnel; etc.

However, a number of these tools have different impacts for facilities with managed lanes. They include:

- impact on managed lanes of public notification of incidents,
- incident responder access path to the incident scene,
- impact of adjacent roadway incidents to managed lane operations,
- general purpose traffic diversion into managed lanes,
- pre-positioned response crews,
- blocking a managed lane to create a safe work area, and
- mutual-aid agreements between managed lane agencies and general purpose lane agencies.

Research Recommendations

The following subsections describe the impacts of the aforementioned incident management tools on facilities with managed lanes in operation.

Multi-agency Cooperation

Where the makeup of the incident response team for the managed lanes is different from that of the nearby general purpose lanes, the potential for poor incident management is heightened. As an example, where an incident on, or immediately upstream of, the ramp to the managed lanes is within the purview of an incident response team that does not have jurisdiction over the managed lanes themselves, the operational efficiency of the managed lanes can suffer, yet the incident response team that is handling the incident may have no accountability to the agency operating the managed lanes. This scenario has financial implications for managed lanes where revenues are generated, e.g., HOT and toll lanes.

Conversely, where an incident in the managed lanes impedes access to the general purpose lanes or frontage road, and the incident response teams differ for the two types of lanes, there is potential for the operations of the general purpose lanes to suffer by the actions of a team that has no accountability for traffic operations in those lanes.

Ideally, the incident response team roles (e.g., policy, fire, emergency medical services, traffic operations, etc.) for the managed lanes team are filled by the same agencies as those for the general purpose lanes; however, because different agencies can have different goals, this is not always the case. In these circumstances, the negative potentials within these scenarios can be mitigated through multi-agency cooperation. Such cooperation can include mutual-aid agreements, hold-harmless agreements, quick clearance policies, abandoned vehicle policies, post-incident briefings, shared information, etc.

Public Notification of an Incident

Sometimes public notification of the clearance of the incident does not happen as rapidly as the notification of the onset of the incident. This delay or omission is likely due to a presumption that the clearance notification is less critical. However, the likelihood that a motorist will choose to use the managed lanes can be significantly reduced as the website and media report that the managed lanes are congested due to an incident in those lanes. Continued reporting of this message after the incident has been cleared reduces the usage of the managed lanes. In cases where the managed lanes are toll or HOT lanes, the erroneous continuation of an incident report, after it has cleared, can unnecessarily create adverse impacts on revenues. This result is in addition to the congestion implications of managed lane-eligible motorists electing to forego the managed lane option and choose to join the congested general purpose lanes.

It is recommended that communications to the public regarding the clearance of an incident in the managed lanes be delivered quickly, just as with messages regarding the beginning of the incident. As with incident management for non-managed lanes, incident management for managed lanes should include coordinating statements to the media through a designated incident response team member, e.g., state department of transportation public information officer. In addition, this designated public information officer should provide regular briefings to other incident response team agencies.

Pre-positioned Response Vehicles

Many incident response teams on non-managed lane facilities use contracted towing companies to clear wreckage from the scene where involved vehicles have become inoperable. The expense of pre-positioning tow trucks at strategically selected locations throughout the corridor is deemed prohibitive.

However, this expense may be worth considering for managed lane facilities that generate revenue. Depending on the specific financial details of a managed lane facility, it may be that the cost of pre-positioning tow trucks, or other response vehicles, is offset by the more rapid response to an incident. If the incident is cleared more quickly and the incident-induced congestion is thereby minimized, then potential toll-paying motorists may choose to use the HOT or toll lane more often. The consideration of deploying pre-positioned tow trucks is an issue of travel time reliability and the resultant beneficial impact on toll revenues.

Creation of a Safe Work Area

When incident response teams arrive at a scene where a one-lane incident is sufficiently severe, it may require closing a second lane to create a safe work area in which the team can maneuver. Where this situation occurs on a facility that includes a non-barrier-separated managed lane, e.g., a concurrent flow HOV lane, and the one-lane incident occurs in the general purpose lane immediately adjacent to the managed lane, a question arises regarding which lane should serve as the second closed lane for the incident response team.

If the managed lane is closed (see Figure 3-13) to create the safe work area, then the managed lane traffic must merge to the right, into the general purpose lanes. This channelization temporarily eliminates the benefits of the managed lane, and it may involve the merging of traffic from a lane operating at higher speeds into lanes operating at lower speeds. The result offers the possibility of secondary collisions.

The alternative is to keep the managed lane open and close the lane to the right of the incident lane. This channelization results in the “safe area” being a temporary island with moving traffic on both the right and left sides of the incident scene. Incident response teams report that the island concept should be avoided for the safety of everyone involved at the scene.

Response Vehicle Access

Where managed lanes are separated from general purpose lanes by a barrier, access to an incident, when congestion levels are high and speeds are slow, can be achieved via traveling on the shoulders. Where the best route to an incident scene is via the lanes on the opposite side of the barrier from the incident, emergency response vehicles can benefit from the use of emergency access points in the barrier.

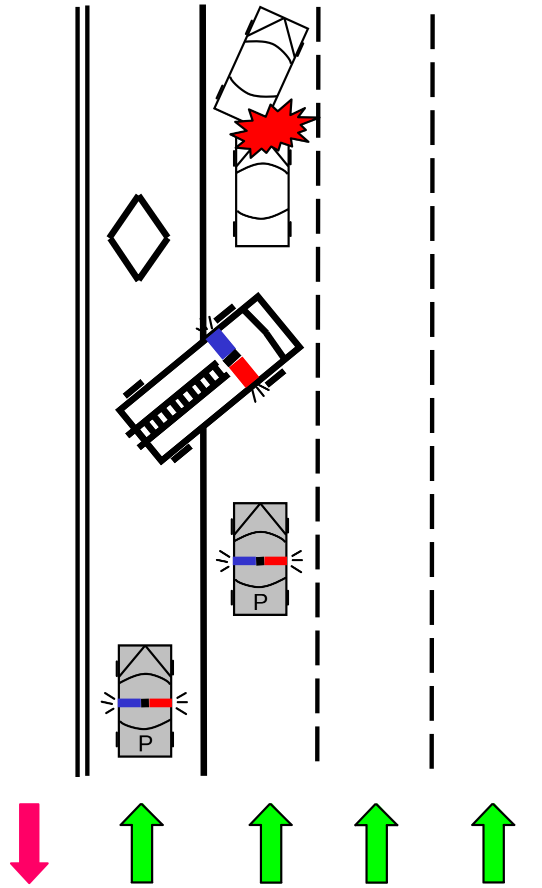

Figure 3-13. "Safe Work Area" Blocking Managed Lanes.

Discussions with incident response team personnel argue against directing response vehicles to travel in a contraflow direction in a managed lane even when it is a one-lane, barrier-separated facility and the lane is completely blocked. Opposition to response vehicle contraflow is based on the high cost (head-on secondary collision) of making an error in reporting that the lane downstream of the incident is clear for a "wrong way" approach. The time required to achieve a sufficient level of certainty may be too great for the contraflow approach to be worthwhile as a time saver. Consequently, unless the managed lane downstream of the complete blockage is absolutely devoid of other moving vehicles, it is recommended that incident response vehicles access the incident scene without traveling in a contraflow direction. The exception to this recommendation is the completely blocked, one-lane, barrier-separated facility that has excellent coverage by closed circuit television (CCTV) cameras and is actively monitored by traffic management center personnel. In this case, emergency vehicle contraflow access to an incident scene may be accomplished with a sufficient level of safety to the responders.

Diversion to Managed Lanes

The first recommendation regarding the diversion plan is that all relevant parties develop it, including all the agencies on the incident response team. Typically this team should include the:

- state department of transportation,
- state law enforcement,
- transit authority,
- incident response team,
- fire department,
- hazardous materials team,
- freeway service patrols,
- emergency medical services,
- local government traffic engineering,
- towing companies,
- medical examiner,
- designated agency's public information office, etc.

The diversion plan should provide for the elimination, or curtailment, of the usual managed lane user eligibility criteria during incidents in the general purpose lanes. These eligibility criteria include vehicle type restrictions, occupancy restrictions, and toll payments.

It is recommended that the diversion plan be deployed if an incident has blocked, or will block, traffic for a specified duration, e.g., 10, 15, or 30 minutes. One managed lane facility operator reported that since they introduced a 10-minute minimum threshold, the managed lane users have issued fewer complaints regarding sharing the lane with general purpose traffic. Agencies report that once the general purpose traffic is allowed to divert into the managed lanes, it is very difficult to "turn it off." Consequently, operators should select the specific threshold based on facility experience. It may be necessary to select the minimum duration such that the frequency of diversion plan deployment is not so often as to motivate managed lane motorists away from regularly using it.

Where the managed lane's physical features and communications infrastructure can support it, it is recommended that the diversion of general purpose traffic into the managed lane cease prior to its reaching an unacceptable congestion level. Report 0-4160-17: *Incident Management on Managed Lanes* *(37)* contains the complete results of this research task.

DEVELOPING RECOMMENDATIONS FOR INTEROPERABILITY WITH EXISTING AND FUTURE TECHNOLOGY

Bringing a managed lanes facility to completion is a complex process of planning, design, and daily operations. Typical ongoing operations include management, enforcement, incident detection, revenue collection, and more. Often, a managed lanes facility is cross-cutting, not only from the multiple types of ongoing operations, but also because it can involve multiple agencies and vehicle user groups.

These types of interactions all point to a level of interoperability heretofore unseen for most roadways. As a definition, interoperability can best be expressed as "the ability of a system to use the parts, information, or equipment of another system." This new level of interoperability raises several questions, such as:

- What are the major areas of interoperability within a managed lane facility?
- What is the scope of each area?
- What are the critical issues associated with each area?

Research Effort

There were three steps in the research approach to this task. The first step was conducting the literature review. The objective of the literature review was to identify the major areas of concern with regard to interoperability. In addition, the literature formed the basis for developing detailed questions for step two of the task.

In step two, the researchers developed a survey based on the knowledge obtained from the literature. The goal of the survey was to use the knowledge of the profession to identify not only the scope of each area of concern but also its relative importance. The survey was developed for ease of use, using an online format to enable researchers to capture input from a large body of potential respondents.

Step three was the culmination of the project, where the results from both the literature and the survey were used to develop the final recommendations for addressing interoperability concerns within the managed lanes manual. In addition, the goal of this step of the task was to produce draft text for each of those sections.

Key Findings

While there were a number of pieces of useful information that resulted from the in-depth literature review, there was one key concept that quickly became apparent – the notion of multiple levels of interoperability. The concept of multiple levels was somewhat opposite the initial thinking that interoperability was a global concept that existed across entire systems. Instead, the literature gave credibility to three levels of interoperability, namely:

- agency,
- facility, and
- equipment.

These three levels, illustrated in Figure 3-14, can essentially be used to provide more structure and definition to the identified interactions.

By defining the levels of interoperability, the focus of the interactions at that level becomes clearer. As an example, agency-level interactions typically consist of long-term planning or design coordination, as well as broad-scale agreements for creating similar policies and procedures for operating managed lane facilities. In sharp contrast to that high-level planning and interaction, coordination at the equipment level is meant to ensure that data elements from one system can be transmitted, received, and understood by another system, regardless of their eventual use in both systems. In the middle of the two endpoints are the facility-level interactions, which typically would occur in areas such as geometric design, traffic control devices, enforcement, and more.

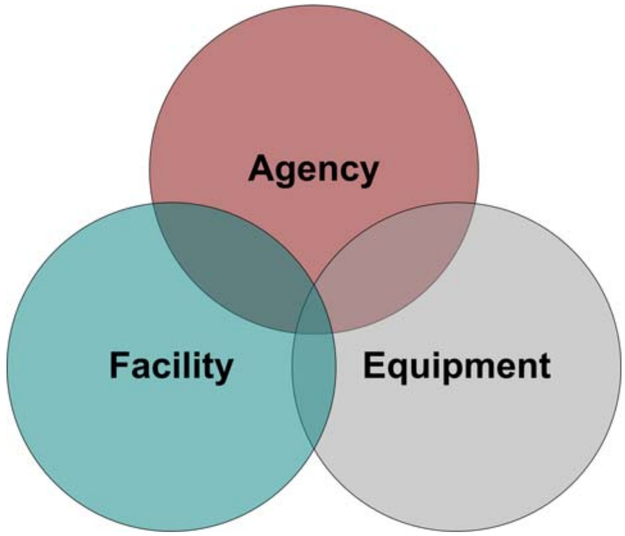

Figure 3-14. Levels of Interoperability.

The results of the literature review provided a solid basis for understanding the broad range of interoperability concerns as well as providing researchers with enough information to construct an initial matrix of areas of interoperability concerns. However, researchers felt that they could obtain more in-depth knowledge from a survey of the profession, where the depth of these interactions could be explored to a greater degree than was present in the literature.

A 24-question survey was constructed and put online at the managed lanes website. Notification of the survey was sent out via newsletters and email listservs to an estimated audience of more than 5300 professionals in the transportation industry. It should, however, be recognized that only a small percentage of the target audience has experience with managed lanes facilities and that a significant response rate was not anticipated. Survey results have been recorded from approximately 0.5 percent of the target audience.

The most significant question of the online survey explored the participants' thoughts on the relative importance of each area of interaction, from "Most Important" to "Least Important." In essence, this survey was a modification of the literature review matrix by allowing five levels of criticality to be assigned to each area. A weighted average technique was used to determine the critical levels associated with each area. Table 3-4 shows the results.

Table 3-4. Refined Matrix of Interoperability Concerns from Online Survey.

	Agency	Facility	Equipment
Geometric Design		✓	
Operations	✳	✓	✳
Enforcement	✳	✳	
Communications	✳		✓
Traffic Control Devices		+	✓
Surveillance & Monitoring		✓	+
Traveler Info Systems	✳	✳	✳
Planning	+	✳	
Incident Management	✓	✓	
Maintenance		✳	
Legislation	✳		
Evaluation	✳		
Agency Staffing & Training	✳		

In Table 3-4, the checkmark (✓) represents the most important or critical interactions. An obvious example to check as a sounding board for validity in the results is geometric design. The results of the survey indicate that participants related that geometric design was most important to coordinate at a facility level. This makes sense since managed lanes have to interact with adjacent facilities through the use of ramps, access lanes, and other geometric features that can only be designed and merged on a per-facility basis. Since all geometric design is developed from national standards, there is no critical need to coordinate across agency levels.

The plus sign (+) in Table 3-4 represents an important area of interoperability. Feedback from the survey indicates that while these areas are important to consider, the failure to do so will not result in a breakdown of the facilities in question, although there may be inefficiencies in operation.

Finally, the asterisk sign (✳) represents those interactions that should be considered in the future. While they are not critically important to the overall design, construction, and operation of the managed lanes, their eventual coordination can lead to increased effectiveness and a better transportation system for motorists.

Research Recommendations

The researchers recommend that the managed lanes handbook address interoperability issues. In particular, text pertaining to interoperability issues should be part of the following sections:

- planning,
- geometric design,
- traffic control devices,
- operations,
- incident management,
- surveillance and monitoring, and
- communications.

In the above listing, although it did not "make the cut" as an important issue, communications has been added. Communications is a critical component of both surveillance and monitoring and traffic control devices at the equipment level; any discussion of interoperability in the handbook would be remiss in neglecting this important facet. The research team published the research results for this task in Report 0-4160-18: *Interoperability Issues on Managed Lanes Facilities (38)*.

DECISION FRAMEWORK FOR SELECTION OF MANAGED LANES STRATEGIES

Motivation for managed lanes has evolved in Texas since the beginning of this research project in 2000. Early emphasis was placed on a broad definition of managed lanes that embraces multiple operating strategies, with pricing (specifically variable toll rates) viewed primarily as one of a number of demand management techniques. At that time little importance was placed on revenue implications. With the passage of HB 3588 by the Texas Legislature in 2003 – legislation that instituted broad sweeping changes in the way Texas highways are financed – a philosophical shift has taken place in the view of managed lanes in the state that places greater emphasis on pricing as a means to offset implementation and operating costs.

Most urban areas in Texas now evaluate managed lanes in existing highway corridors, partially as a means to offer travel options but also as a mechanism for implementing new departmental policy that requires evaluating all new capacity for tolling. Revenue expectations for managed lanes have been predictably low, particularly for single-lane directional facilities.

In these situations, cost recovery is typically expected to be such that it covers operations and possibly a small portion of capital costs. TxDOT has nonetheless adopted the approach that revenue generated from tolling new lanes is a prudent policy – freeing up funding that would have otherwise been needed for facility operations and maintenance. This paradigm shift within the department translates into an evolution of the original expectations of the research project since its inception five years ago. The philosophical shift, however, potentially leads to more widespread implementation of managed lanes in Texas than would have otherwise naturally developed, albeit with a greater emphasis on the revenue-producing benefits of the facility.

Research Effort

This task conducted research that documents the development of a decision support methodology that accomplishes two objectives: (1) sorting out the relationships between managed lanes concepts and strategies, and (2) mapping the knowledge territory in order to identify gaps. In conjunction with this particular research task, a user-friendly preliminary screening tool was developed to assist TxDOT in identifying managed lane strategy options very early in the conceptual planning process. The framework for the decision support methodology is the backbone for the *Managed Lanes Handbook*, which offers the resources and guidance to develop a managed lanes project, addressing characteristics unique to individual facilities.

Key Findings

The first step in developing a decision support process was the construction of the flow chart presented in Figure 3-15. The flow chart maps the general project development process with additional elements unique to managed lanes: identification of managed lanes operating strategy and potential user groups. Even with the evolution of TxDOT's philosophy on managed lanes over the course of the project, the flow diagram remains relevant.

Additionally, Figure 3-16 provides a simplified version of the flow diagram. The intent of this research task was to develop a decision framework for the upper area of the flow chart – to identify potential managed lanes strategies for a corridor based on the project's goals and objectives and to use the project objectives coupled with corridor influences to narrow the strategy list.

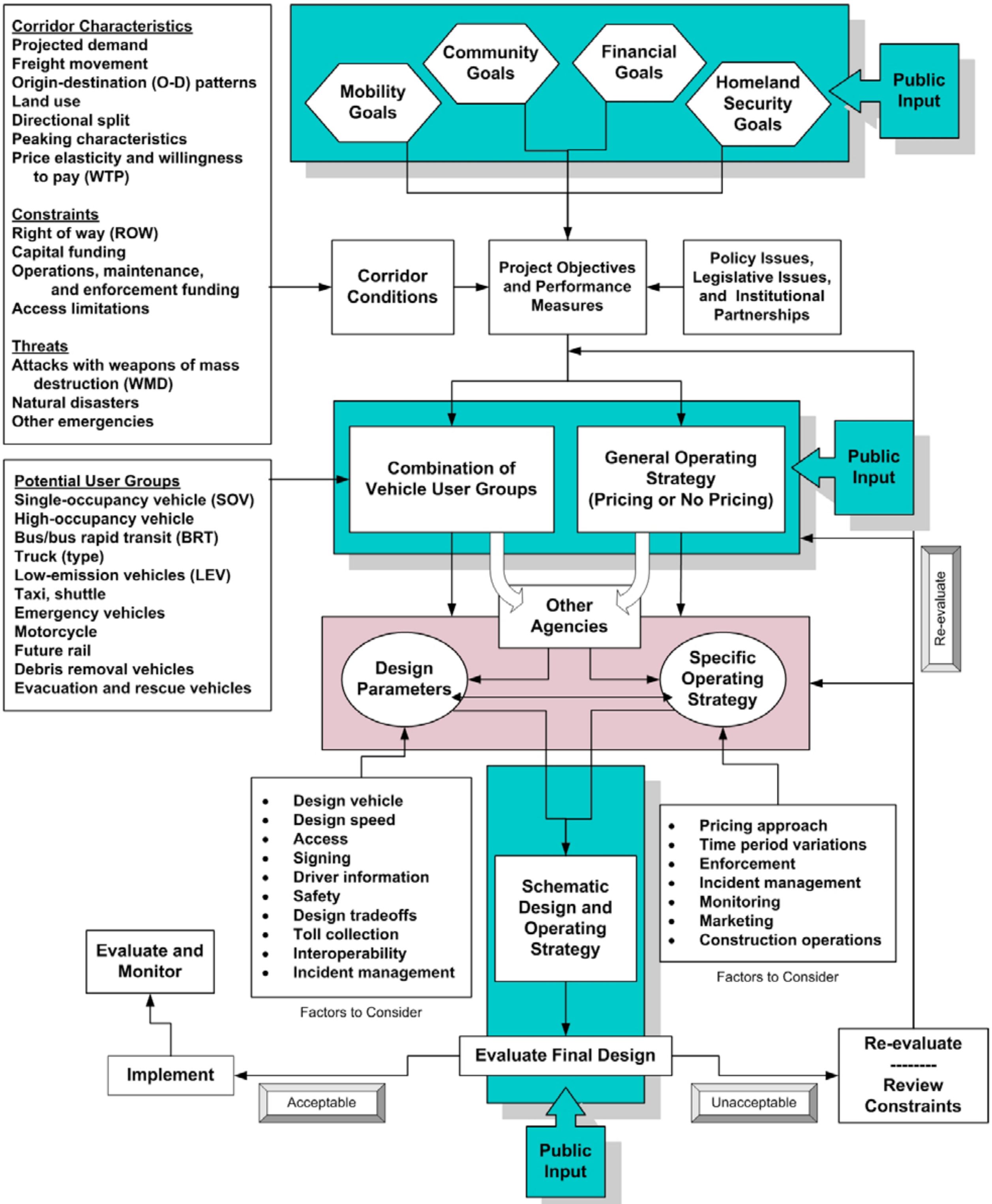

Figure 3-15. Managed Lanes Development Process.

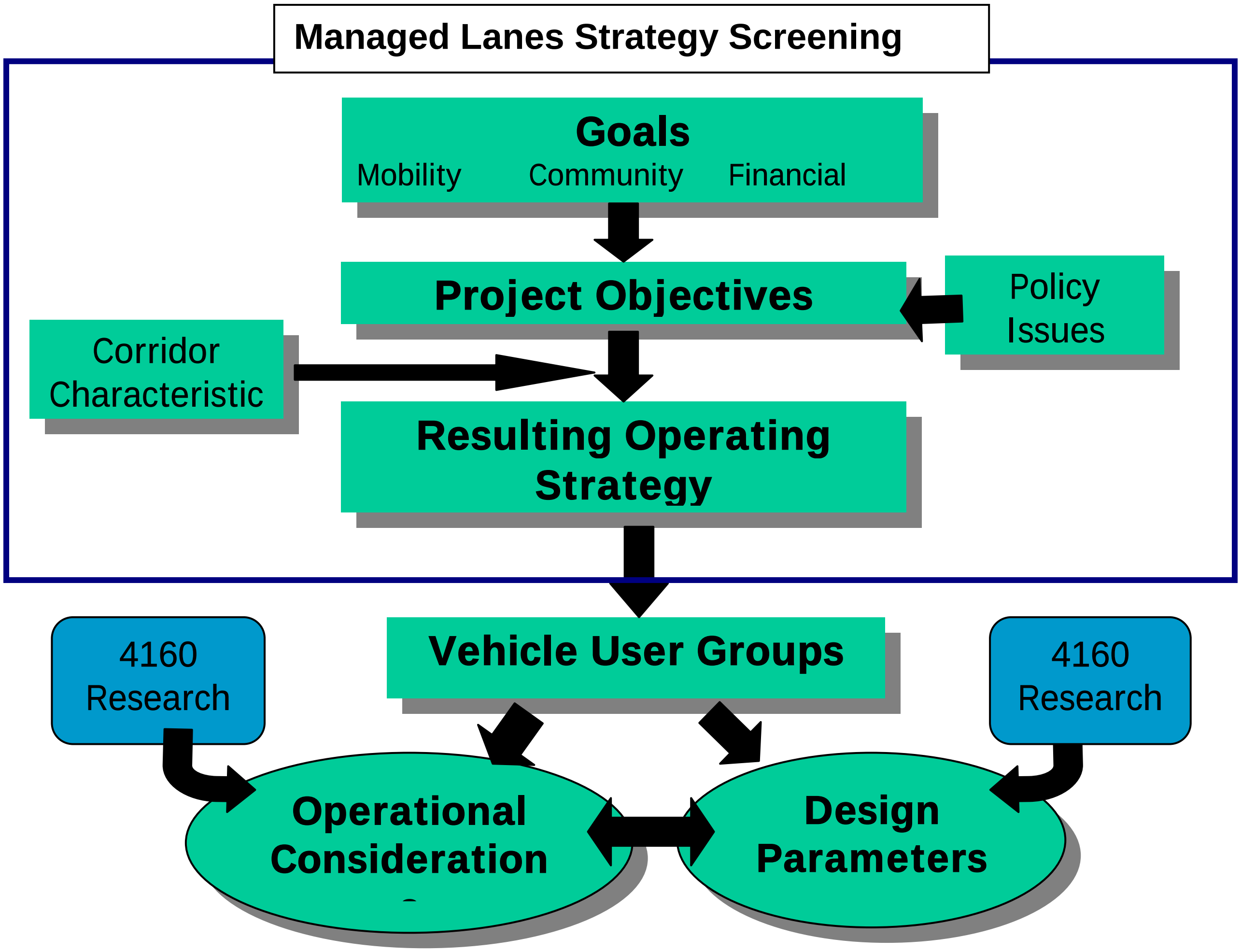

Figure 3-16. Flow Diagram Showing Elements of the Decision Process Incorporated into the Strategy Selection Tool.

The bottom portion of the simplified flow chart shows that operational considerations and design parameters come into play once the operating strategy and resulting user groups are defined. The other tasks for the larger 0-4160 research effort support the lower boxes of the flow diagram with development steps that involve the design of the facility and the operational components necessary for implementation. These steps are briefly highlighted below and can be found in more detail in the *Managed Lanes Handbook*:

- Geometric design – access type and spacing, weaving distances.
- Traffic control devices – signs and markings for driver information.

- Enforcement – approaches for ensuring compliance.
- Incident management – guidance for operational approaches.
- Interim use – use of managed lanes under special situations.
- Evaluation and monitoring – guidance for post-project monitoring.
- Staffing and training – staffing needs given complexities of operation.

The purpose of the strategy selection tool is to provide a preliminary screening instrument for TxDOT project managers to use that helps define the types of managed lane strategies conducive for a given corridor. It is a simple tool that primarily relies on the defined objectives for the improvements in defining the potential operating strategies. It was created to facilitate the decision-making process by identifying potential managed lanes scenarios to implement. The program incorporates many different calculations to determine the best possible scenario based upon the objectives chosen by the user. It is important to note that it is a very quick and simple tool for designers to use early in the planning process to help sort out possible managed lanes operating scenarios.

Research Recommendations

The overall goals for the implementation of managed lanes can be divided into three distinct groups: mobility goals, community goals, and financial goals. The mobility goals of managed lanes focus on such wide topics as demand and accessibility and are characterized as such because they aim to improve the mobility of the facility or system in question. Community goals are generally defined as goals that aim to help maintain or improve the local community based on the interests of its constituents. Financial goals, much like their name implies, are goals that aim to address the financial realities of infrastructure expansion with limited funding, and the financing methods by which an agency pursues the development of projects.

The overall objectives of various managed lanes can be linked to individual objectives they are trying to achieve. Initially, the screening tool gathers input from the user in the form of objectives a user wishes to address. The 19 objectives available for the user to select for the screening tool are as follows:

(1) Increase Vehicle Carrying Capacity,

(2) Increase Person Carrying Capacity,

(3) Increase Goods Carrying Capacity,

(4) Maintain Free Flow Speeds,
(5) Maintain or Improve the LOS,
(6) Reduce Travel Time,
(7) Increase Trip Reliability,
(8) Provide Travel Alternatives,
(9) Reduce Peak Period Vehicle Trips,
(10) Improve Express Bus Service,
(11) Provide Transmodal Connectivity and Accessibility,
(12) Minimize Traffic Crashes Involving Large Trucks,
(13) Improve Air Quality from Mobile Sources,
(14) Address Environmental Justice Concerns,
(15) Encourage Transit Oriented Development,
(16) Fund New Transit and Managed Lanes Improvements,
(17) Produce Enough Revenue to Cover operations and maintenance and Enforcement,
(18) Produce Enough Revenue to Cover Debt Services, and
(19) Private Investment Return on Investment.

These objectives relate to different managed lane strategies, a relationship based on surveys of practitioners and experts. An initial weighted table for the values associated with the objectives gathered from the expert survey was developed. This array forms the basis for the decision process that identifies the strategies that are a best fit for the objectives selected by the user.

The user then enables the weighting process that places greater importance upon some of the objectives, while diminishing the importance of others. By weighting the objectives themselves, the user places more emphasis upon specific objectives, thereby allowing them to have a much more fine-tuned result.

The screening tool user is then presented with a list of constraints that must be filled out to rule out possible managed lanes scenarios from being provided to the user at the conclusion of the program. There are 24 general constraints that are directly tied to the seven possible managed lane strategies, which include such constraints as:

- right-of-way,

- freight and trucking characteristics of the facility,
- congestion index,
- transit and rail service in the corridor, and
- political opposition to tolls in the region.

The reason for the constraints is that the strategies advocated by the experts were too close in some fields, most notably truck traffic and financial considerations. So, the constraints were identified to separate the possible strategies to determine whether or not trucks, and also tolling, should be advocated.

The screening tool takes all of the input and offers three strategy options and their scoring by taking the values associated with the objectives and totaling them to determine which possible scenario best meets the criteria of the user. The constraints are then applied depending upon the user's preference, and the final array is completed containing all of the possible strategies listed in order of acceptability.

Once an operating strategy or multiple operating strategies are identified, defining vehicle user groups for a managed lane facility is the next important step in the managed lanes development process because it:

- helps evaluate financing for the project if non-paying or exempt users are identified;
- establishes the design vehicle used to control the geometrics of the facility design elements;
- offers insight into driver communication and signing needs, especially if the user group can be categorized as a familiar, semi-familiar, or non-familiar user;
- offers insight into potential enforcement opportunities and challenges; and
- provides a starting point for establishing a long-term "concept of operations," where variations in user eligibility can be illustrated over time in order to maintain operational performance thresholds and communicate expected changes over time.

The complete documentation of the task research and screening tool are published in Report 0-4160-21: *Decision Framework for Selection of Managed Lanes Strategies* (39).

STAFFING AND TRAINING NEEDS FOR MANAGED LANES FACILITIES

Managed lane facilities present many new challenges to the agency or agencies responsible for their operation. Because of the potential complexities associated with user groups and operational options, agencies must have an appropriate number of qualified staff members to ensure adequate oversight of operations and to ensure satisfactory customer service to the users. Thus, the task documented in this report was to identify those staffing needs related to operational options and specific training that might be required to ensure those staff members are fully prepared to perform their duties to the satisfaction of both the agency and the customer. Other issues addressed in this report will be the roles of job positions within the framework of managed lanes, the competencies required of those positions, and accessibility to appropriate training, education, and technical assistance to ensure these needs are met.

Research Effort

Researchers worked to identify staffing needs related to managed lanes operational options and specific training that personnel might require ensuring that they are fully prepared to perform their duties to the satisfaction of both the managing agency and the customer. Researchers also reviewed the current accessibility to appropriate training, education, and technical assistance to ensure training needs are met.

Researchers approached this task from two different directions. The first was to identify current training opportunities that are relevant to managed lanes operations. To achieve this approach, researchers reviewed current course listings to catalog current course titles and their main objectives or topic areas. They accomplished the bulk of this approach through an Internet search of currently known administrators of transportation-related training and outreach.

Second, researchers contacted agencies who currently operate managed lanes facilities. They undertook this effort to identify:

- current and future staffing levels and positions within their agencies, and
- training undertaken by the agency prior to opening their facility to current operations.

Often times, agencies alter managed lanes facilities from previous strategies, such as HOV lanes converted to HOT lanes. Researchers also queried the agencies regarding their activities related to staffing and training for these facilities prior to these changes.

Key Findings

The results from this task fall into two categories: available courses and current practice. The following sections highlight the key findings in these categories.

Available Courses

Researchers identified five courses and two seminars/conferences that have aspects or topics related to managed lanes. The five courses identified were:

- High Occupancy Vehicle (HOV) Facilities (Provider: National Highway Institute),
- Corridor Management (Provider: Consortium for ITS Training and Education),
- Strategies for Urban Congestion Workshop (Provider: Northwestern University Center for Public Safety),
- Context Sensitive Solutions (Provider: Northwestern University Center for Public Safety), and
- Electronic Payment Systems (Provider: Consortium for ITS Training and Education).

The two seminars/conferences identified as related to managed lanes were:

- 12th International HOV Systems Conference and
- USDOT Road Pricing Seminar.

Overall, decision makers are the primary audience for the training courses. Primarily, the courses specified transportation professionals in the positions of engineers, planners, or other management or supervisory roles would benefit from the courses. This target audience solidifies the idea that the topics covered are not necessarily related to day-to-day operations of the facilities but rather apply to decisions regarding how, when, or where to implement different strategies and how to identify the appropriate conditions for those strategies. One exception to this idea is the course on electronic payment systems, which specifies field staff as a possible audience for the topic. The basis of this course is more focused upon the understanding of applications and technologies related to the topic.

While not all of these courses and seminars are specifically for managed lanes strategies, some provide information on various elements of managed lanes that have been discussed throughout this report. Also, while their availability may vary over time, they represent possible opportunities for personnel to gain the knowledge, skills, and abilities necessary to perform their role within the operating agency. They do not represent an exhaustive list. Rather, they serve as examples of the topics available that may serve the needs of managed lanes facility personnel. Courses that are similar in nature can suffice if available.

Current Practice

Researchers contacted representatives from several different agencies currently operating, or planning to soon open, managed lanes facilities. Due to the limited number of areas where specific managed lanes schemes have been implemented, researchers selected a limited number of agencies to contact during this task. Researchers identified the agencies contacted as those that are most familiar with managed lanes facilities. Through these interviews, researchers garnered valuable insights into the current staffing and training approaches utilized for the facilities. From these conversations, researchers gathered information from two systems that are currently in active operations of a managed lanes facility and one that is planning to open a facility by the end of the year.

Representatives from the active managed lanes facilities indicated that the primary responsibility of the managing agency was to oversee contract management for the managed lanes. Also, they utilized their existing public relations and marketing personnel to assist with the public outreach aspect of the managed lanes. With regard to the customer service aspect of managed lanes operations, both of the agencies outsource this work and do not have a direct hand in the day-to-day customer service for the facility. One agency provided information that their outsource contractor has five employees who work exclusively on the operations of the managed lane customer service. Two of these staff are in management roles, and the other three are customer service representatives handling relations with the customers.

Training for the customer service staff of the managed lanes facilities was not a primary responsibility of the managing agencies, as this work is outsourced to different contractors. However, one agency did cite that an operations plan developed by the initial contract operator outlines the policy considerations and their outcomes and customer service staff guidance for handling a variety of transactional and service-related questions for the responsible personnel. This plan also provides guidance on the use of a proprietary software application that was developed to host the account and transactional data.

There were differences within the agencies spoken to in the handling of traffic operations and incident management for the managed lane facilities. One of the agencies did this work within their organization and had done a limited amount of training to ensure that the personnel working in the local TMC were familiar with the managed lanes operation and their role in that operation. This training consisted of a two-hour group seminar to review procedures. The Minnesota Department of Transportation (MnDOT) also incorporated this information into their training of new TMC personnel. The second agency which has an active and mature HOT system does not have responsibility for local traffic operations and incident management, as the operation of the area TMC is not within their jurisdiction. It was noted by this agency that if this arrangement was ever to shift and these roles became the responsibility of the agency, extensive training would be required to ensure that the personnel charged with these duties gained the expertise required for these positions.

Research Recommendations

To date, training practices are currently limited with regards to managed lanes facilities. However, a number of skill sets or knowledge bases exist that should be met to ensure smooth operations of a managed lanes facility. These skill sets include:

- contract management and supervision,
- customer service relations,
- accounts handling,
- traffic operations management,
- incident management, and
- public relations and marketing.

For agencies operating managed lanes facilities, skilled personnel should be identified within the agencies. Otherwise agency directors should see that appropriate personnel receive training as to the startup of operations or secure appropriate personnel through outsourcing. The research team published the research results for this task in Report 0-4160-20: *Staffing and Training Needs for Managed Lanes Facilities (40)*.

STRATEGIES FOR INTERIM USE OF MANAGED LANES

Although managed lanes largely function under their intended standard operating procedures (derived from goals and objectives set earlier in the planning process and related to mobility and congestion, reliability, accessibility, safety, environmental impact, system preservation, or organizational efficiency), certain conditions may require unusual interim use of the facilities. Such conditions may include:

- construction or maintenance activities that result in either a long-term reduction in capacity or a severe, short-term reduction in capacity;
- special events that result in a severe, short-term increase in traffic demand;
- major incidents that result in either a long-term reduction in capacity or a severe, short-term reduction in capacity; and
- large-scale emergencies and evacuation that result in either a long-term or severe, short-term increase in traffic demand.

Since interim use of managed lanes may detract from the facilities' intended use and performance, carefully crafted interim use policies developed in the planning stages should guide decisions for the short-term use of managed lanes.

Research Effort

Given the lack of formal policies or guidelines, variability in observed practices, and limited understanding of potential benefits or concerns surrounding interim use of managed lanes, the objectives of this task were to:

- discern any positive trends in interim use procedures for managed lanes (i.e., in published literature or observed practice) that could be recommended for widespread implementation;
- identify and describe potential benefits and concerns surrounding interim use of managed lanes; and
- assimilate this information into recommended guidelines addressing all aspects of managed lane facility interim use.

This information forms the basis of the recommendations contained in the *Managed Lanes Handbook* developed for TxDOT. To accomplish the objectives of this task, researchers reviewed published literature and current research to discern any positive trends in interim use procedures for managed lanes that they could recommend for widespread implementation and to identify potential benefits and concerns surrounding interim use of managed lanes. Researchers also reviewed national practice related to interim use of managed lane facilities.

Key Findings

The novelty of managed lanes as a traffic management strategy, the diversity of managed lane facility types (i.e., high-occupancy vehicle lanes, exclusive truck lanes, etc.), and the breadth of motivating factors for interim use (i.e., construction and maintenance, special events, etc.) challenged the identification of pertinent literature or current research. Hence, much of the literature reviewed was only indirectly related to interim use of managed lane facilities. When conducting a review of national interim managed lane use practices, researchers encountered:

- similar limitations related to the novelty of managed lanes as a traffic management strategy,
- the diversity of managed lane facility types, and
- the breadth of motivating factors for interim use.

Research Recommendations

A set of criteria that defines when a managed lane facility should be open for interim use is imperative to provide consistency in operation under non-standard conditions, and with the managing transportation agency's policies and priorities for the facility (i.e., to preserve a higher level of service for managed lane users). These interim use criteria must be tailored to each facility but, in general, should consider the following:

- severity and nature of the conditions;
- time of day, anticipated duration, and anticipated traffic impacts; and
- availability of alternative facilities or strategies.

Table 3-5 provides a summary of general recommendations considering each of these criteria.

While beneficial in lending consistency to practice, interim use criteria for managed lanes cannot account for every situation and location. Therefore, the decision to utilize managed lane facilities under interim use still relies upon the good judgment and experience of on-site personnel.

Table 3-5. Recommended Interim Use Criteria

Criteria		Recommendation
Severity and Nature of Conditions	Emergencies and Evacuation	Recommended
	Major Incidents	Recommended with carefully defined criteria for interim use
	Construction or Maintenance	Not recommended; if necessary, schedule to minimize performance impacts (i.e., nighttime construction)
	Special Events	Not recommended
Time of Day	Morning Peak	Not recommended; both the managed lane and general purpose lanes are congested and travel time reliability is key to managed lane users
	Midday	Recommended if the level of congestion in the managed lane is less than the level of congestion in the general purpose lanes
	Evening Peak	Not recommended; both the managed lane and general purpose lanes are congested and travel time reliability is key to managed lane users
	Nighttime	Not recommended; both the managed lane and general purpose lanes are uncongested
Anticipated Duration and Traffic Impacts	Locally Defined	Define in terms of event duration and lanes impacted; interim use strategy may vary by time of day Criteria may be dynamic to control frequency of interim use 24-hour managed lane facilities should resume normal operation as soon as possible following an event Peak period or extended operations should continue interim use through the remainder of the operational period to simplify enforcement
Availability of Alternative Facilities or Strategies	Locally Defined	Use of alternative facilities and of alternative operational strategies on the general purpose facility (i.e., shoulder travel) should be considered prior to interim managed lane use Use of alternative facilities is preferred; alternative operational strategies may compromise design or safety standards

In addition to identifying when interim managed lane use should occur, it is important to determine how interim managed lane use should occur, including any accompanying actions that support implementation. Important considerations related to inter-agency communication and coordination, on-site signing and traffic control, network traffic management, public education, and monitoring and evaluation are summarized in the following sections.

Inter-agency Communications and Coordination

The following are important considerations related to inter-agency communications and coordination for managed lanes interim use:

- For interim managed lane use under major incident or emergency conditions, a communication and coordination linkage between law enforcement and transportation agencies is critical.
- Communication and coordination between law enforcement and transportation agencies are challenged both by protocol and technological limitations (i.e., interoperable radio systems). Protocol-based challenges can be overcome through inter-agency training and inter-agency coordination agreements but may require a change in agency policy. Technological challenges may be overcome by exchanging radio units, using cellular telephones, or communicating through a centrally accessible traffic or emergency operations center. In either case, pre-planning should occur to overcome these challenges prior to an event.

On-Site Signing and Traffic Control

The following are important considerations related to on-site signing and traffic control for managed lanes interim use:

- During managed lane interim use, traditional channelizing devices (i.e., cones, tubes, barrels, and barricades) and lane control signals or flashers can be used to indicate interim managed lane use.
- Traffic control devices must be accompanied by adequate signing, directing a motorist to the managed lane and also directing the motorist out of the managed lane, either downstream of the event or following its termination.

- Clear and concise information, including the reason for diversion to the managed lane facility, whether the diversion is voluntary or mandatory, length of time or distance that the motorist is allowed to continue to drive on the managed lane, and availability of entrance and exit points, if the managed lane facility is physically separated from the general purpose facility, must be presented to reduce any confusion for the motorist.
- Temporary static signs or portable or permanent changeable message signs (CMS) can be used to relay limited information to the motoring public.
- Portable or permanent Highway Advisory Radio (HAR) or commercial media can supplement the information provided through signing.
- A working relationship and cooperative agreements with the media should be in place prior to an event to establish a protocol for communications and to stress the importance of accurate real-time information.

Network Traffic Management

The following are important considerations related to network traffic management for managed lanes interim use:

- Traffic management or emergency operations centers, through the use of closed circuit television cameras or other surveillance technologies, can monitor traffic on the managed lane and general purpose facility, upstream and downstream of the affected facility and along alternative routes, to better identify and remedy potential problems and to support decisions related to a return to standard operation for the managed lane facility.
- Even if the managed lane facility is open for interim use by general purpose traffic, many motorists will opt to take alternate local routes rather than the managed lane facility. Hence, early and continuous communication with the local jurisdictions regarding the state of the general purpose and managed lane facility is important.

Public Education

The following are important considerations related to public education for managed lanes interim use:

- For general public education, prevalent national practice is to provide general information regarding their interim managed lane use practices via the World Wide Web. Most often, this information is contained as a response to a "frequently asked question" on the agency's website.

Monitoring and Evaluation

The following are important considerations related to monitoring and evaluation for managed lanes interim use:

- Monitoring and evaluation of interim use strategies will support decisions related to the conditions under which interim use is implemented (i.e., the duration and impact of an incident) and will provide the necessary information to justify these decisions.
- Performance metrics for interim managed lane use should relate to the intent of the motivating event and should include: congestion levels on both the managed lane and general purpose facility before and during interim use, safety of both motorists and responders, and public acceptance/perception.
- Congestion levels, expressed in terms of vehicles per hour per lane, travel time, travel speed, etc., can be monitored by a traffic management center using surveillance technologies (i.e., electronic loop detectors, closed-circuit television cameras, etc.). A minor compromise in the managed lane level of service and a corresponding improvement in the general purpose facility level of service are desirable. A dramatic decrease in the managed lane level of service may suggest a re-evaluation of interim managed lane use criteria or discontinued interim use, especially if a negligible change is observed on the general purpose facility.
- Safety information can be obtained through accident records for the motoring public and through agency on-the-job injury reports for responders. A separate record of secondary incidents should be maintained; accident records do not distinguish secondary incidents. An improvement in responder safety suggests

continuation of managed lane interim use. These observations should be tempered with any observed increase in motorist-involved incidents at managed lane ingress or egress points or elsewhere along the facility attributable to motorist unfamiliarity or confusion. An increase in motorist-involved incidents at these locations suggests a need for improved signing and traffic control at these locations or may prompt discontinued interim use of the managed lane facility.

- Lastly, a survey of users and non-users of the managed lane facility should be performed to determine the public's opinion on whether the managed lane should have been opened to general traffic. This survey can be conducted as an online survey or, depending on the nature of the managed lane facility, can be distributed in hardcopy form.

For this information to be of greatest use, managing agencies need to define local conditions leading to appropriate interim managed lane use. This recommendation includes defining appropriate times of day when congestion levels would support interim managed lane use (i.e., excess capacity in the managed lane, congestion in the general purpose lane, etc.) and identifying and investigating the suitability of alternative facilities or operational strategies that could be utilized in place of or in conjunction with interim managed lane use. The complete results of this research task are included in Report 0-4160-22: *Strategies for Interim Use of Managed Lanes* (41).

EVALUATION AND MONITORING OF MANAGED LANES FACILITIES

Successful performance monitoring and evaluation activities support an agency's provision of day-to-day services, direct facility and administrative management decisions, and guide short- and long-range planning efforts. Despite not-so-recent legislative or regulatory mandates requiring performance monitoring as an eligibility criteria for federal funding of transportation projects, transportation agencies have been challenged to adequately monitor and evaluate transportation facility performance.

Much of the progress made in addressing the challenges of monitoring and evaluation challenges, developing performance measures, and refining evaluation methods has considered general freeway facilities. Current reference guides on this topic address site-specific to corridor-level operations analysis, alternative investments analysis, area-wide planning, and public information studies for a variety of strategies used for freeway management and operations.

While these guides are comprehensive in topic, they lack specificity for managed lane facilities. Managed lane facilities are unique, typically requiring a higher degree of active (sometimes real-time) management, addressing goals and objectives that are inconsistent with the general freeway facility (i.e., revenue generation, person rather than vehicle throughput, etc.), and accessing an exclusive set of management tools (i.e., gate closures, etc.). These differences may affect how managed lane facility performance is successfully monitored and evaluated.

Research Effort

To address the potential differences between managed lane facilities and general freeway facilities, this investigation was conducted to isolate and document the best performance monitoring and evaluation practices and principles explicitly for managed lanes facilities. More specifically, the objectives of this task were to:

- identify positive performance monitoring and evaluation practices for managed lanes (i.e., in published literature or observed practice) that could be recommended for widespread implementation;
- document reportable managed lane benefits that may guide the development of performance "benchmarks" for monitoring and evaluation;
- identify and describe any issues for consideration surrounding performance monitoring and evaluation practices for managed lanes; and
- assimilate this information into recommended guidelines addressing all aspects of managed lane facility performance monitoring and evaluation.

This information will form the basis of the recommendations contained in the *Managed Lanes Handbook* developed for TxDOT and FHWA.

To accomplish the objectives of this task related to the monitoring and evaluation of managed lane performance, a review of published literature and ongoing research was conducted to:

- identify positive practices that could be recommended for widespread implementation,
- identify and describe any issues for consideration surrounding these practices, and

- document reportable benefits to support development of performance "benchmarks."

Researchers primarily utilized the Transportation Research Information Services (TRIS) online database and the Transportation Research Board's Research in Progress (RIP) database to identify appropriate published literature and ongoing research.

Key Findings

Much of the progress made in advancing the state-of-the-practice in performance monitoring and evaluation has considered general freeway facilities. While this information is useful, it lacks specificity for managed lane facilities. Managed lane facilities are unique, typically requiring a higher degree of active (sometimes real-time) management, addressing goals and objectives that are inconsistent with the general freeway facility (i.e., revenue generation, person rather than vehicle throughput, etc.), and accessing an exclusive set of management tools (i.e., gate closures, etc.). These differences may affect how managed lane facility performance is successfully monitored and evaluated.

In response largely to TEA-21's requirements for performance monitoring as an eligibility criterion for receipt of federal funding, a number of studies were conducted in the 1990s that focused on guiding or enhancing these activities. These seminal studies culminated in the development of national guidelines for general freeway performance monitoring and evaluation. The *Freeway Management and Operations Handbook* (*42*) considers a broader spectrum of topics but devotes one chapter to describing best practices for freeway performance monitoring and evaluation. In addition, the National Transportation Operations Coalition recently published results from its *Performance Measurement Initiative* that detail a short list of recommended performance measures that can be used for internal agency management, external communications, and comparative measurement. Most recently and currently under development, *NCHRP 3-68: Guide to Effective Freeway Performance Measurement* (*43*) provides comprehensive direction for defining and utilizing freeway performance measures and developing a comprehensive freeway performance management program.

This investigation relied heavily upon the guidance provided in these recent documents to ensure consistency with national performance monitoring and evaluation guidelines and to reflect prior lessons learned for these activities. The following sections contain notable findings and recommendations related to each step of the step-by-step performance monitoring and evaluation process.

Goals and Objectives

For transportation facilities, including managed lanes, goals and objectives typically focus on: mobility and congestion, reliability, accessibility, safety, environmental impacts, system preservation, and/or organizational efficiency. With these various focus areas in mind, successful goals and objectives should:

- be measurable and quantifiable, adequately describing changes in operation;
- consider performance at the system, project, agency, regional, or statewide level and involve the public, local business interests, elected officials, and agency personnel;
- drive the data to be collected, not be driven by data availability;
- consider qualitative (i.e., related to customer satisfaction) goals; and
- prioritize conflicting goals (i.e., system preservation goals may require an increase in maintenance expenditures while agency efficiency goals seek to minimize maintenance costs).

Performance Measures

Similar principles for success exist when defining related performance measures. To be successful, performance measures should be:

- limited in number to prevent data collection and analytical requirements from overwhelming an agency's resources or decision makers;
- simple and understandable with consistent definitions and interpretations to address the needs of a wide-ranging audience, while still achieving the required precision, accuracy, and detail to facilitate system or program improvement;
- easily captured either automatically using various technologies or manually with minimal manual data entry and processing to produce usable results;
- sensitive to change and able to adequately capture observed changes in system or program performance;

- consistent with staff skills (simplistic evaluation methods with accurate results are preferred over advanced methods that may be erroneous if staff are not adequately trained);
- consistent in timeframe with decision-making needs, ranging from real time to long term; and
- geographically appropriate with decision-making needs, ranging from corridor specific to region wide, statewide, or even nationwide.

Emerging trends or "principles" in the selection of performance measures for transportation facilities are as follows:

- mobility measures should be based on travel time (travel time, or other similar derivatives of speed and delay, is easily understood by practitioners and the public and is applicable to both the user and facility perspectives of performance);
- multiple metrics should be used to report performance;
- traditional *HCM*-based performance measures (volume-to-capacity ratio and level of service) should not be ignored but should serve as supplementary, not primary, measures of performance in most cases;
- both vehicle-based and person-based performance measures should be developed (person-based measures provide a "mode-neutral" way of comparing alternatives);
- both mobility and efficiency performance measures should be developed with improvements in efficiency linked to positive changes in mobility;
- customer satisfaction measures should be included;
- three dimensions of freeway congestion should be tracked with mobility measures: source of congestion, temporal aspects, and spatial detail; and
- the buffer index – the amount of extra time needed to be "on time" 95 percent of the time – is emerging as the preferred reliability measure.

Data Collection

Three general categories of data are generally collected to support transportation facility performance monitoring and evaluation: facility use and performance data (i.e., traffic volumes, travel times, and delay); staffing and resource allocation and use data; and event and incident data, including location, duration, and nature. Data can be collected through a variety of means including automatic or manual techniques. Further, data can be collected continuously across a facility or sampled through special studies. Notable lessons learned with respect to data collection are as follows:

- Automatic techniques may suffer from reliability problems and questionable accuracy. It is essential to confirm the accuracy of automatically collected data by periodic use of manual devices.
- Special studies are typically short in duration and generally focused on collecting data (i.e., vehicle occupancy and transit ridership information) not available through existing sources. Care must be taken to avoid bias when utilizing special studies sampled data.
- To capture motorist perception data, focus groups, stated preference surveys, or revealed preference surveys can be used. Each has advantages and disadvantages that should be considered related to the level of information provided and the potential for extrapolation to a larger population.
- When selecting data collection methods, the cost and accuracy of each method, the availability of local resources to implement each method, the ease of implementation, and the ultimate data analysis requirements should be considered.

Monitoring and Evaluation

Evaluation activities may range from a simplistic analysis of quantitative measures to produce descriptive or inferential statistics to any number of more comprehensive, robust analyses related to capacity and level of service, simulation, before-after effects, or alternatives selection. Capacity analysis and simulation are appropriate for ongoing system monitoring, while before-after and alternatives analysis are more appropriate for evaluation prior to or following implementation.

The required frequency of evaluation (i.e., monitoring) is variable and highly dependent upon the amount of variation observed for a particular facility and constraints upon agency resources. In general:

- continuously collected data (i.e., traffic volumes, travel times, etc.) should be analyzed monthly, quarterly, and/or annually;
- continuously collected data should be compared with supplemental manually collected data (i.e., from travel time studies) at a monthly or quarterly frequency to ensure adequate data quality (higher frequencies of comparisons are required if significant inconsistencies are observed);
- data that have infrequent occurrences (i.e., accidents) should be analyzed annually or every two to three years; and
- similarly, data that require considerable data collection resources (i.e., customer satisfaction surveys) should be analyzed annually or every two to three years.

In each case, the frequency of evaluation (i.e., monitoring) can decline over time as the facility performance stabilizes.

Reporting

The audience for performance monitoring and evaluation information is broad but can be effectively categorized by jurisdictional levels:

- local, requiring real-time information to select and implement operational plans, provide traveler information, and plan future improvements;
- regional, requiring aggregated real-time information to address the performance of the system and implement and monitor regional response plans;
- state, requiring information specific enough to distinguish modal performance for resource allocation and programming and long-range planning; and
- national, requiring long-term, aggregate information to determine net effect of strategies, support policy making and goal setting, develop/justify legislation, etc.

Common media and formats for relaying performance monitoring and evaluation information include:

- real-time websites providing specific traveler information (i.e., incidents, etc.);
- operations planning reports supporting daily road or transit operations;
- annual, monthly, and quarterly reports summarizing regional or statewide conditions, recent performance, and trends;

- before-after and issue studies focusing on corridors, times of day, or specific problems (i.e., travel time variations, freight movement, etc.);
- project analysis reports, used to support public transportation, operational, or demand management programs, describing total system effects; and
- long-range planning reports providing trend information and travel forecasts, along with more typical planning measures.

Research Recommendations

Despite the novelty of managed lanes as a traffic management strategy, the diversity of managed lane facility types, and the breadth of motivating factors for managed lane implementation, some general consistency in practice was observed with respect to performance monitoring and evaluation. Common goals, objectives, and performance measures were observed across similar facility types. Significant differences were also observed across similar facility types with respect to observed performance outcomes and evaluation methodologies. Differences in observed performance outcomes are likely explained by the variety in facility design (i.e., length of facility, accessibility, etc.) and operation (i.e., eligibility requirements, toll rates, etc.), even within a similar facility type. Differences in the evaluation methodologies used to arrive at these observed performance outcomes are likely reflective of the available resources for analysis at the time of evaluation and the evolving state of analysis methodologies.

With a focus on the commonalities across similar facility types, Table 3-6 depicts typical goals, objectives, and performance measures for the various managed lane facilities considered as part of this investigation. Note that, in general, passenger-focused managed lane facilities have a primary interest in increasing (person) throughput, reflected as a function of increased average vehicle occupancies and increased travel speeds. Encouraging the mode shift to higher occupancy vehicles is the potential for travel time savings and travel time reliability. Value-priced and HOT lanes present unique opportunities for toll revenue, capitalizing on the time savings benefit with less emphasis on encouraging mode shift. Safety and environmental effects are of secondary interest, primarily reported to confirm no adverse impacts from implementation of a managed lane facility. Accidents generally occur infrequently and, hence, require a lengthy evaluation period. Environmental effects are loosely estimated as a function of travel speeds.

Table 3-6. Common Goals, Objectives, and Performance Measures for Managed Lane Facilities.

GOALS/OBJECTIVES		PERFORMANCE MEASURES	MANAGED LANE FACILITIES: HOV Lanes	Value-Priced and HOT Lanes	Exclusive Lanes		Mixed-Flow Separation/Bypass Lanes		Lane Restrictions	Dual Facilities
			Passenger	Passenger	Passenger	Freight	Passenger	Freight	Freight	Passenger and Freight
MOBILITY/CONGESTION	Increase overall mobility during recurring and nonrecurring congestion while maintaining accessibility									
	Increase throughput	• Daily and hourly volume on mainlane (ML) facilities (vehicle, person volumes) • Total, daily, and hourly facility volume (general purpose, ML, other) • Total, daily, and hourly facility volume (vehicle, person, truck volumes) • Vehicle-, person-, or truck-hours of travel • Vehicle-, person-, or truck-miles of travel	P	P	P	P	P	S	S	P
		• Percent peak period volume (vehicle, person, truck volumes)	S		S		S			S
		• Per lane efficiency (speed x pphpl)	S		S					S
		• Vehicle occupancy (per/veh)	P	S	S		P			S
		• Temporal shift		P						
		• Transit ridership • Carpool use • Transit market share	P		P		P			P
		• Mode shift	S	P	S		S			S
	Increase average travel speeds	• Average lane (ML and GP) and facility speed	P	S	P	P	S	S	S	P
	Decrease average travel times	• Travel time rate (minutes per mile)	S		S					S
		• Travel time savings per mile • Annual travel time savings ($)	P	S	P	P	P	S	S	P
		• Customer perceptions on travel time	S	S	S	S	S	S	S	S
	Decrease delay	• Average delay (day and annually) • Average delay (vehicle, person, and ton-mile)		S			P	S	S	
	Decrease violators	• ML compliance	P	S	S	S	P	S	S	S
RELIABILITY	Increase reliability during recurring and nonrecurring congestion									
	Decrease travel time variation	• Std. deviation (travel time, speed) • Variance (coefficient of variation, travel time, speed)	P	S	P	P	P	S	S	P
		• Customer perceptions on reliability	S	S	S	S	S	S	S	S

P=primary, S=secondary

Table 3-6. Common Goals, Objectives, and Performance Measures for Managed Lane Facilities (continued).

GOALS/OBJECTIVES		PERFORMANCE MEASURES	MANAGED LANE FACILITIES: HOV Lanes	Value-Priced and HOT Lanes	Exclusive Lanes		Mixed-Flow Separation/Bypass Lanes		Lane Restrictions	Dual Facilities
			Passenger	Passenger	Passenger	Freight	Passenger	Freight	Freight	Passenger and Freight
REL.	Increase "on-time" performance	• Buffer index (95th percentile travel time by corridor and major trip) • Percent of trips that arrive in acceptable time window	P	S	P	P	P	S	S	P
SAFETY	Increase overall safety levels									
SAFETY	Decrease the frequency and severity of incidents	• Number of incidents (by type and location) • Incident severity • Incident reduction savings ($)	S	S	S	P	S	P	P	P
ENVIRON.	Decrease overall impacts to the environment and resources									
ENVIRON.	Decrease fuel consumption	• Fuel consumption (per person miles of travel [PMT], vehicle miles of travel [VMT], or truck miles of travel [TMT])	S	S	S	S	S	S	S	S
ENVIRON.	Increase air quality/ decrease pollutants	• Tons of pollutants • Number of days in air quality non-compliance	S	S	S	S	S	S	S	S
SYSTEM PRESERV.	Maintain or increase overall system service life									
SYSTEM PRESERV.	Decrease deficient facilities	• Pavement deterioration rate change • Remaining service life				P		S	P	P
SYSTEM PRESERV.	Decrease deficient facilities	• Roughness index for pavements • Percent of roads with deficient ride quality (VMT, TMT) • Percent of roadway pavement rated good or better				S		S	S	S
SYSTEM PRESERV.	Decrease deficient facilities	• Maintenance costs per year				P		S	P	P
ORGANIZ. EFFICIENCY	Increase productivity without compromising public's expectations for efficient and effective travel									
ORGANIZ. EFFICIENCY	Increase customer satisfaction ratings	• Percentage of projects rated good to excellent • Qualitative customer comments	S	S	S	S	S	S	S	S
ORGANIZ. EFFICIENCY	Minimize costs	• Cost for construction (per lane-mile, VMT, PMT, or TMT)	P	S	P	P	P	P	S	P
ORGANIZ. EFFICIENCY	Minimize costs	• Vehicle operating costs (per lane-mile, VMT, PMT, or TMT)	P	S	P	P	P	P	P	P
ORGANIZ. EFFICIENCY	Minimize costs	• Cost-benefit measures	P	P	P	P	P	P	P	P
ORGANIZ. EFFICIENCY	Maximize revenue	• Toll revenue		P		P		P		

P=primary, S=secondary

Freight-focused managed lane facilities, on the other hand, often have a primary interest in safety and a unique interest in preserving the pavement infrastructure. Resulting benefits attributable to time savings are secondary in nature. Hence, freight-focused opportunities for toll revenue (i.e., exclusive lanes and mixed-flow separation/bypass lanes) report limited likely success.

The complete results of this research task are included in Report 0-4160-23: *Monitoring and Evaluating Managed Lane Facility Performance (44)*.

REVISIONS AND ADDITIONS TO THE TRAFFIC OPERATIONS MANUAL

The *Highway Operations* volume (*45*) of TxDOT's *Traffic Operations Manual* (*46*) is a document that TxDOT engineers and personnel can use to plan, design, operate, and enforce highways within their jurisdiction. As the document currently stands, little is included regarding the issues associated with managed lanes. Researchers began assessing this document to identify recommendations for revisions and/or additions to this document to enhance its applicability and use by TxDOT personnel. However, upon greater inspection of the document, the research team determined that the entire document was in need of updating and revision.

The Traffic Operations Division of TxDOT canvassed the districts to determine to what extent staff use this document in their daily work, the result being that few staff members regularly use this document. The Traffic Operations Division decided that a complete revision of the document would not be cost-effective given its limited use. Thus, the project director agreed to terminate this task. Researchers ceased work on this task after TxDOT approved a modification requesting elimination of this task and the related deliverable.

FACILITATING THE UPDATE OF THE AASHTO GUIDE FOR HOV FACILITIES AND GUIDE FOR PARK-AND-RIDE FACILITIES

The objective of this task was to assist AASHTO in updating the *Guide for the Design of High-Occupancy Vehicle Facilities* (*47*) and the *Guide for the Design of Park-and-Ride Facilities* (*48*). There are significant additional experiences and research in these areas that needed to be incorporated into the guides since they were last published in 1992. National Cooperative Highway Research Program (NCHRP) 20-7 funding also supports work conducted under this task.

The Task Force for Public Transportation Facilities Design of the AASHTO Subcommittee on Design was responsible for updating the guides. The Task Force held their first meeting at the end of May 2001 to discuss the revision activities with TTI facilitating. Task Force members were assigned as leaders to sections of the HOV guide to update them as needed. In the fall of 2001, the Task Force section leaders identified areas within their sections that required the most extensive changes. Subsequently, the Task Force leaders updated their sections of the HOV guide and submitted their initial drafts of the updated sections to TTI in early 2002.

After receiving the updated changes from the Task Force, the TTI research team then began editing and organizing the sections of the HOV guide. The research team also developed some sections that were not assigned to Task Force members and provided additional text to enhance the flow of the document. The primary references used for the update to the new HOV guide were the NCHRP *HOV Systems Manual (32)*, the TxDOT-sponsored Guidance for *Planning, Operating, and Designing Managed Lane Facilities in Texas (26), the previous* AASHTO HOV and park-and-ride guides listed above (*47, 48*), and the AASHTO *Green Book* (*27*). The *Park-and-Ride Planning and Design Guidelines* (*49*) published by Parsons Brinckerhoff was used to assist in the update of the park-and-ride guide. Finally, TTI updated all figures and photographs throughout both guides.

The research team completed a first draft of both guides by the end of August 2002. The research team then distributed copies of the drafts to the Task Force by September 1, 2002. At a meeting with the Task Force in October 2002, the research team obtained comments on both guides. Based on the comments, the second draft of each guide was distributed to the Task Force and to a peer review team in March 2003.

The research team received comments on the second draft of each guide by May 2003. The research team critically reviewed the comments, questions, and suggestions received. The third draft was released in the fall of 2003 to the Task Force for any final comments. Final comments were incorporated into the documents, and AASHTO published the guides in the fall of 2004.

DEVELOPING A MANAGED LANES HANDBOOK

To assist in implementation of the managed lanes research results of this project, particularly in areas that are in the beginning phase of planning such a project, the research team developed the *Managed Lanes Handbook* (*50*). This document includes all of the research in a usable format, providing a clear, concise, and step-wise approach to planning, designing, operating, and enforcing a managed lanes facility. It also refers the user to other pertinent documents that provide additional detailed information on various aspects of managed lanes.

CHAPTER 4: GAPS IDENTIFIED IN THE MANAGED LANES RESEARCH

The five-year managed lanes research effort focused largely on design and operations issues associated with managed lanes, and delved to a lesser degree into some of the policy, legislative, financial, and public outreach concerns. While the managed lanes research program has offered TxDOT direct guidance for application in current project development, the program has also identified new challenges and areas for further exploration. Of particular interest are the second generation projects that are incorporating managed lanes as a mobility strategy encompassing a broad range of operational possibilities, challenges, and complexities. Each of the new challenges pose tough questions that have not been tackled in the projects currently in operation.

As the findings of the managed lanes research have been developed over the five-year effort, the remaining questions raised in each topic area have been documented and in many cases folded into the RMC research development process. As a result, several upcoming research projects will address some of these gaps, in whole or in part. Each of those projects is described in the section that follows. The subsequent section provides a full listing of all the gaps identified as a result of this research and highlights whether the gap will be addressed in one of the upcoming research projects.

NEW RESEARCH PROJECTS

The following sections summarize new research efforts that emerged from this project.

Research Project 0-5284: Feasibility and Guidelines for Applying Managed Lane Strategies to Ramps (RMC 4)

Congestion in all of the major urban areas in Texas continues to increase, and the need for new roads to address this congestion exceeds not only the funding capacity but the ability to gain environmental and public approval for large-scale construction projects. TxDOT needs to continue considering alternative solutions to roadway widening to mitigate the adverse effects of congestion. One of the areas for potentially improving freeway performance is at ramp locations. Current ramp treatments only address point demand. The application of managed lane operational strategies to ramps could maximize existing capacity, manage demand, offer choices, improve safety, and generate revenue within the freeway itself. This project will investigate the application of these demand management strategies to mainlane and managed lane ramp operations during the peak period, i.e., "managed ramps." Such demand management techniques include time-of-day restrictions, vehicle type restrictions, and value pricing. This research would investigate under what conditions managed ramps should be considered for both mainlanes and managed lanes based on relevant factors including target users in the corridor, congestion level, ramp spacing/density, ramp volumes, accident history, etc.; provide general guidelines/best practices for operating and enforcing managed ramps; and assess the impacts and benefits of managed ramps.

Research Project 0-5286: The Role of Preferential Carpool Treatment in Managed Lane Facilities (RMC 2)

High-occupancy vehicle facilities are an important element of the transportation systems in Houston and Dallas, and are being considered in other metropolitan areas in the state. The Texas Department of Transportation and partnering agencies have learned a great deal about the design, operation, and enforcement of HOV lanes over the past three decades. With the evolution of HOV facilities to managed lanes, and the increasing level of activity in the development of managed lanes in Texas and nationally, there is a need for research and guidance defining the role of carpools in priced managed lanes and the tradeoffs between carpool exemptions and other project objectives. Increasingly, project objectives are reflecting not only mobility concerns but funding deficiencies and the need to generate revenue. As a result, allowing exempt users such as carpools requires an evaluation of revenue impacts as well as mobility interests such as person movement, operations, and emissions. This research will help identify the benefits, drawbacks, and tradeoffs of providing preferential treatment for carpools and vanpools in managed lane facilities.

Research Project 0-5426: Best Practices for Separation Devices between Toll and Free Lanes (RMC 4)

Agencies have installed various types of treatments to separate tolls lanes from general purpose lanes at existing projects and are looking at options for future projects. Advice on the location of the access and egress to and from toll lanes is also needed. Limited information is available on the treatments used to separate toll lanes from general purpose lanes. However, there is much information available from decades of experience with HOV lanes, both in Texas and nationally. Although the notion of tolling HOV lanes by converting them to HOT lanes is a recent phenomenon, the basic design framework associated with operating an HOV lane is the same as a separated toll lane or managed lane. The primary differences are related to tolling infrastructure.   This research project is to investigate the following three topics: characteristics of treatments used to separate toll lanes from general purpose lanes (pavement markings, delineators, and concrete barriers), access and egress to toll lanes, and location of access and egress to toll lanes with respect to other ramps. This product will allow TxDOT engineers to readily evaluate different treatments that are available for use in separating toll lanes from the general purpose lanes and to understand the tradeoffs in selecting the location of the access points to the toll lanes.

Research Project 0-5446: Guidelines for Signs and Markings on Toll Roads (RMC 4)

The first part of this project will evaluate current toll road signing practices and identify deficiencies and inconsistencies. The research activities will include a review of signing practices on toll roads in other states and internationally, assessments of driver information needs, and development of recommendations to improve signing and markings on electronic toll collection facilities, at toll plazas, and at access points from other freeways and arterials. The second part of this project will conduct driver comprehension research of proposed sign designs and sign sequences. Pavement marking longitudinal striping patterns and horizontal signing (i.e., words and symbols on the pavement) will also be studied. Many toll facilities are experimenting with novel colors of signs and the use of toll authority logos on signs and pavement markings. The effect of these treatments on drivers has not been assessed. The last part of this project will develop guidelines for the selection, design, and placement of signs on toll roads.

RESEARCH GAPS

A summary of the research gaps is provided in Tables 4-1 and 4-2. Table 4-1 lists the planning and policy research needs, and indicates whether one of the upcoming TxDOT or current FHWA research projects will address it. Table 4-2 lists the design and operations research needs associated with managed lanes, and also provides an indication of inclusion in one of the funded research efforts.

Table 4-1. Planning and Policy Research Gaps and Identified Research Studies.

Research Gap	Research Project to Address Gap
The role of revenue generation and the competing objectives of maximizing person movement through HOV exemptions and maximizing revenue generated by the project	0-5286 Role of Preferential Carpool Treatments in Managed Lane Facilities
The role of bus transit, including BRT, and its integration in managed lane operations	May be examined under 0-5286 Role of Preferential Carpool Treatments in Managed Lane Facilities
Analytical tools that estimate travel demand, revenue projections, and operational impacts interactively	Partially addressed through 0-4818 Managed Lanes Revenue Model, but the research did not include interactive analysis of operational impacts
Evaluation of managed lanes in the National Environmental Policy Act analysis, including the relationship of managed lanes to purpose and need, revenue forecasts versus regional forecasts, and how managed lanes are considered in the alternatives analysis and fiscal constraint analysis	None
Evaluation of public/private initiatives involving managed lanes	None
Equity and environmental justice concerns, including burden of cost, distribution of funds, and geographic equity	None
Legislative authority, particularly related to operating agencies and their powers to operate as toll authorities in collecting fines and enforcing compliance using automated techniques	May be examined under 0-5286 Role of Preferential Carpool Treatments in Managed Lane Facilities; also being examined by FHWA through HOV Pooled Fund Study (PFS) project (refer to PFS website)
Integration of managed lane projects into the existing and planned transportation system (freeway, arterial, and transit systems) and connectivity with other managed lanes	None
Feasibility and application of truck-only toll lanes	Project statement submitted as a potential RMC 2 project in FY 07
Economic impact of communities served by managed lanes	None

Table 4-2. Design and Operations Research Gaps and Identified Research Studies

Research Gap	Research Project to Address Gap
Multiple mid-point ingress/egress points and the ripple effect on technical and operational complexity, including tolling operations, lane separation, enforcement, safety, and driver information	Access points in relation to lane separation will be examined under 0-5446 Best Practices for Separation Devices between Toll Lanes and Free Lanes
The safety implications of buffer or striped separation between managed and general purpose lanes, and the ability to effectively enforce access restrictions and toll evasion	0-5446 Best Practices for Separation Devices between Toll Lanes and Free Lanes
The design of managed lanes facility termini and impacts on the overall system, in terms of delay, travel time, and safety	None
Design and operations of single-lane directional managed lanes, including passing over long distances and best application of pricing strategies	Project statement submitted as a potential RMC 2 project in FY 07
Improved methods for enforcement of HOV preference in managed lanes – technological, procedural, and institutional	Will be examined under 0-5286 Role of Preferential Carpool Treatments in Managed Lane Facilities
Signing and motorist information needs in an operating environment where strategies may change dynamically and where competition with signing in adjacent freeway lanes may create driver information overload	0-5446 Guidelines for Signs and Markings on Toll Roads; also being examined by FHWA through managed lanes research (refer to FHWA website)
Sustaining operational flexibility over the life cycle of the facility, and communicating to policy makers and the public that freeway express lane operations will be adjusted as needed over time according to pre-defined performance objectives	None
Dynamic operations beyond pricing, including methods and approaches to dynamically modify vehicle eligibility or access on a managed lane facility	Access methods to be examined under 0-5284 Feasibility and Guidelines for Applying Managed Lane Strategies to Ramps

CHAPTER 5: FINAL REMARKS

Throughout the entire length of this research project, the researchers took a team approach to completing their work, ensuring efforts were not duplicated and the results were comprehensive and cohesive. When the project began, managed lanes was a term that many had not heard of and knew very little about. As the project progressed, researchers investigated many of the questions surrounding the topic and the operation of these unique facilities. Though new questions emerged from the research, the end result was a productive and illuminating five-year effort that found critical pieces to the complex puzzle of managed lanes. Furthermore, the timing of the project helped propel TxDOT to the forefront of managed lanes research, illustrating their insight and vision of the future of capacity management and their leadership role in advancing the state-of-the-art and state-of-the-practice in freeway operations in the United States. The solid foundation created by this project will long serve the transportation profession as a springboard to seek answers to new questions about managed lanes. It also will help move managed lanes forward in step with new technology and in an environment that requires transportation professionals to be increasingly prudent in their investment in the transportation network and the management of that resource to ensure mobility for all.

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