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URL: http://tti.tamu.edu/documents/0-4160-19.pdf 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 managed lane operations are proposed. 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 summarizes the activities of the first four years of this multiyear project, highlights the accomplishments to date, provides a status report of efforts underway, and outlines planned activities for the coming year.				
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YEAR 4 ANNUAL REPORT OF PROGRESS: OPERATING FREEWAYS WITH MANAGED LANES

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> Performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration

> > September 2004

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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. This project was conducted in cooperation with the Texas Department of Transportation (TxDOT) and the U.S. Department of Transportation, Federal Highway Administration (FHWA). The contents do not necessarily reflect the official view or policies of the Federal Highway Administration or the Texas Department of Transportation. The 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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CHAPTER 1: INTRODUCTION

BACKGROUND

The increasing population growth in Texas has placed 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 lanes" (high-occupancy toll). Recently, transportation agencies are becoming 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.

With the exception of pure HOV lanes, the knowledge base for all forms of managed lane projects is very limited. In addition to the Katy (IH-10) and Northwest (US 290) QuickRide projects, two other similar projects are also in operation in the United States: the IH-15 FasTrak

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project in San Diego and the SR 91 Express Lanes project in Orange County, California. Both projects have extensive evaluation programs that are examining 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 lane operational approach will offer peak-period freeflow travel to certain user groups. These user groups might be HOVs, trucks, toll-paying vehicles, transit, low-emitting vehicles, or some combination of these and other groups. The current HOT lane pilot project 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. These studies include, but are not limited to, the following:

- Northwest Freeway (US 290) in Houston,
- Northeast Corridor (IH-35) in San Antonio,
- SH 121/114 in Fort Worth,
- Loop 1/US 183 in Austin, and
- IH-35 in Waco.

In at least four 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 are in agreement as to where the project is going and what the final product that will facilitate the implementation of research results will be.

The research supervisors, in collaboration with the Texas Transportation Institute (TTI) Advisory Council, identified the *vision* of managed lanes research as it relates to TxDOT. This vision is to develop a better understanding of how managed lanes can improve mobility for transportation system users. The *objective* of this managed lanes project is to investigate the complex and interrelated issues surrounding the safe and efficient operation of managed lanes and to develop a managed lanes manual 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 are 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 intends to answer. These questions, as provided in Table 1-1, represent a comprehensive, though not exhaustive, look at the intended results of the project.

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Managed Lanes Project Phase	Critical Question to Be Answered
Managed Lanes Project Phase Planning Managed Lanes Facilities	Critical Question to Be Answered 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?

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

PROJECT MANAGEMENT STRATEGY

The complex nature of this project requires a well-defined and coordinated project management strategy. The project management team structure outlined in Figure 1-1 provides for TxDOT oversight and guidance from the program coordinator, project director, and project monitoring committee. It also provides 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 Daniels, head of the Austin Office of TTI, lead the research team. Ad hoc technical advisory committees support specific tasks within the research effort and have 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 lead the various project tasks with guidance from the research supervisors and task-related technical advisory committees.



Figure 1-1. Project Management Organization.

TxDOT Project Monitoring Committee

The project monitoring committee (PMC), composed of seven district engineers and seven engineers from various TxDOT divisions, assists the project director, the program coordinator, and the project team in directing the project to meet the needs of TxDOT. The PMC participates in the annual TxDOT workshop, provides input regarding the work plan and critical research needs, and ensures that the overall objectives of the project are met.

External Stakeholder Committee

The external stakeholder committee has 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 works with the project team to see that the stakeholder interests and concerns are considered throughout the project. The intent is to ensure the future buy-in of these stakeholders to managed lanes projects in the state.

Texas Transportation Institute Advisory Committee

TTI provides 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 meets 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 allows the committee to be directly involved in the project in the most efficient and effective manner possible. The committee's involvement helps to ensure that no aspect of the operation of managed lanes is overlooked and the best possible results are reached.

Technical Advisory Committees

TxDOT staff from various districts and divisions as well as other related stakeholder organizations participate in ad-hoc technical advisory committees throughout the course of the project. Researchers assemble these committees on a task basis, and the task leaders charge the members with providing technical insight and guidance to the project team for that task. This strategy ensures that the research team meets particular needs of the districts, divisions, and

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organizations in a manner that works with the TxDOT process while meeting the objectives of managed lanes.

RESEARCH PLAN AND TIMELINE

The TTI work plan is a general road map to aid TxDOT and the research team in managing a successful project. The process established and the people involved enable refinement of the details updates to the road map to meet TxDOT's needs as the project unfolds. Because of the newness of the concepts and the evolution of research principles, researchers will base work beyond the first three years on the results to date. Working closely with the TxDOT project monitoring committee and the TTI advisory committee during the annual modification process, the project team will develop detailed work plans for subsequent years one year prior to conducting the research so that the tasks and desired research can be refined to reflect the previous results and the needs of TxDOT. Table 1-2 provides a summary of the project tasks and their anticipated start date by year.

Status	Task		
Complete	Review Current Practice and State-of-the-Practice Literature		
	Plan and Host a Managed Lanes Symposium		
	Analyze Operational Scenarios Based on User Group(s)		
	Develop Recommendations for Geometric Design of Managed Lanes		
	Develop a Concept Marketing Strategy		
	Identify State and Federal Legislative Changes or Requirements Needed		
	Develop Recommendations for Funding and Financing of Managed Lanes		
	Develop Recommendations for Enforcement Procedures and Design		
	Provide Recommendations for Changes to AASHTO HOV and Park-and-Ride Design Guides		
	Identify Traveler Information and Decision-Making Needs		
	Develop Recommendations for Traffic Control Devices for Managed Lanes		
	Develop a Framework for Optimum Incident Management		
	Develop Recommendations for Interoperability with Existing and Future Technology		
Underway	Develop a Decision Matrix for Consideration of Design and Operational Options		
	Develop Managed Lanes Manual		
	Plan and Host Annual Workshops for TxDOT PMC		
Planned for	Provide Recommendations for Staffing and Training Needs		
2005	Develop Strategies for Interim Managed Lane Use during Construction and Other Situations		
	Develop Recommendations for Evaluation and Monitoring of Managed Lanes		

Table 1-2.	Schedule of Project Tasks.
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CHAPTER 2: ONGOING ACTIVITIES

The research team works 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 to date.

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 ongoing research that TTI is conducting for TxDOT on managed lanes, provides key research results and access to related products, has information on meetings and other events related to managed lanes across the country, and has 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 home page for the website.



Figure 2-1. Managed Lanes Website.

QUARTERLY NEWSLETTER

To assist implementation, the project team publishes a quarterly newsletter to document lessons learned throughout the duration of the project. This newsletter, *FastLane*, allows department engineers and other key personnel quick access to implementable research findings without having to wait until completion of the project. The team publishes the newsletter electronically, with the approval of the project director (PD), and distributes it to the project mailing list of over 300 transportation professionals. The researchers reach an even broader audience by posting the newsletter on the project website. Figure 2-2 illustrates the format of the newsletter. To date, the research team has published eight newsletters with positive feedback from readers.



The interoperability Research Team and TTI Managed Lanes Project Team would like to take this opportunity to thank all the respondents, who participated in the research process by filling out the interoperability survey. The responses contained a great deal of useful information and added substantial knowledge to the project. The final report on this portion of the project is being completed and will be available on-line at the managed lanes web site in the near future.

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

improving metropolitan

mobility and accessibility. The

conference will be held in Houston in the Spring of 2005.

CONTACT WITH PROJECT REPRESENTATIVES

The project team continues to periodically contact TxDOT staff who are instrumental in the various managed lanes projects across the state. Since the inception of this project, the research team has 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. The research team anticipates that they will have similar meetings in the future as they complete research tasks.

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

Researchers also help disseminate research results through presentations, abstracts, and technical papers. Whether at the local, state, national, or international level, these tools serve as powerful allies in giving practitioners access to the latest information to help them in their respective organizations. Since the beginning of this project, researchers have made presentations to and/or prepared technical papers for numerous conferences, meetings, and organizations, as highlighted in Table 2-1. Additionally, the research team provides monthly status reports to the project director and program coordinator and prepares additional products and items that assist with the research effort and disseminate research results. Table 2-1 summarizes all of these items as well as the project's official deliverables. The research team anticipates continuing this effort to help ensure that the research results reach the practitioner in a timely manner and to expedite implementation both in Texas and across the nation.

Type of Product	Description / Title / Event
	Fiscal Year 2004
Reports	Proceedings of Annual Workshops for TxDOT (FHWA/TX-04/4160-3)Meeting Summary: 2003 Annual Project Monitoring Committee WorkshopTask 13 Report: Traveler Information Needs (FHWA/TX-04/4160-13)Identification of Traveler Information and Decision-Making Needs for Managed Lane UsersTask 14 Report: Interim Managed Lanes Manual (FHWA/TX-04/4160-14)Interim Manual for Managed LanesAnnual Research Report: Year 3 (FHWA/TX-04/4160-15)Year 3 Annual Report of Progress: Operating Freeways with Managed Lanes

 Table 2-1. Published Project Deliverables and Products to Date.

Type of Product	Description / Title / Event
	Fiscal Year 2004 (continued)
Reports (continued)	Task 15 Report: Traffic Control Devices (FHWA/TX-04/4160-16) Traffic Control Devices for 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)
Newsletters	Traffic Control Devices for Managed Lanes (4160-16B) FastLane – Fall 2003
INEWSIEllers	FastLane - Fail 2003 FastLane - Spring 2004
Articles	Managed Lanes: The Future of Freeways, <i>TexITE Newsletter, Summer 2004</i>
Abstracts	Managed Lanes Research in Texas, Transportation Research Board (TRB) Third International Symposium on Highway Design
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, 7 th Annual Texas Transportation Summit, August 2004*
Status Reports	Monthly Status Report – September 2003
Ĩ	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
Tech Memos	Monthly Status Report – August 2004 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

Type of Product	Description / Title / Event
	Fiscal Year 2003 (continued)
Reports	Task 7 Report: Sample State and Federal Legislation (FHWA/TX-03/4160-8)
(continued)	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
	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)
T 1	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)
Bulletins	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
ive wsietters	FastLane – Winter 2003
	FastLane – Spring 2003
	FastLane – Summer 2003
Articles	The Future of Freeways: Research Identifies Strategies for Developing Managed Lanes, <i>Texas</i>
1 introles	Transportation Researcher, Vol. 39, No. 2
	Managed Lanes: A New Concept for Freeway Travel, <i>The Dunn Deal</i> , Issue #9, May 2003
D 11'1 1	State Legislative Issues for Managed Lanes in Texas, 2003 TRB Annual Meeting
Published	Managed Lanes Research in Texas, 2003 Institute of Transportation Engineers (ITE) Annual
Papers	Meeting
Unpublished	A Legislative Framework for Operating Managed Lanes, 11th International HOV Conference
Papers	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, 11 th International HOV Conference, October 2002

Type of Product	Description / Title / Event
	Fiscal Year 2003 (continued)
Presentations	Managed Lanes – Operational Issues and Design Treatments, 11 th International HOV
(continued)	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*
	Weaving Recommendations for Managed Lanes, 2003 TRB Annual Meeting, January 2003*
	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	Research Supervisor Semiannual Progress Report – February 2003
Reports	Research Supervisor Semiannual Progress Report – August 2003
Status Reports	Monthly Status Report – September 2002
1	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

Type of Product	Description / Title / Event
Fiscal Year 2002 (continued)	
Reports	Task 8 Report: Concept Marketing Strategy (FHWA/TX-02/4160-7)
(continued)	Marketing the Managed Lanes Concept
Products	Position Paper for Key Policy Makers (FHWA/TX-02/4160-P1)
l .	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)
Newsletters	Managed Lanes: A New Concept for Freeway Travel: A Position Paper for the Media FastLane – August 2001
newsietters	FastLane – December 2001
	FastLane – March 2002
	FastLane – June 2002
Articles	Managed Lanes, <i>Transportation Management + Engineering</i> , December 2001/January 2002
	Managed Lanes Offer Choices, Flexibility, Texas Transportation Researcher, Vol. 38, No. 2
Unpublished	State Legislative Isssues for Managed Lanes in Texas, 2003 TRB Annual Meeting
Papers	Weaving Recommendations for Managed Lanes, 2003 TRB Annual Meeting
Abstracts	Concept Marketing of Managed Lanes, 11th International HOV Conference
	A Legislative Framework for Operating Managed Lanes, 11th International HOV Conference
	Life-Cycle Graphical Representation of Managed HOV Lane Evolution, 11 th International
	HOV Conference
	Weaving Lengths for Managed Lanes Access and Egress, 11 th International HOV Conference
Descentations	Managed Lanes in Texas: A New Strategy, 11 th International HOV Conference Operating Freeways with Managed Lanes, RMC 2 Meeting, November 2001
Presentations	Marketing Managed Lanes in Texas, 2002 TRB Annual Meeting*, January 2002
	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, 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
0 1	Managed Lane Concept, 2002 Texas Transportation Summit, August 2002
Semiannual	Research Supervisor Semiannual Progress Report – February 2002 Research Supervisor Semiannual Progress Report – August 2002
Reports Status Reports	Monthly Status Report – September 2001
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
T I. M	Monthly Status Report – August 2002
Tech Memos	Current State of the Practice (TTI TM 4160-4)

Type of Product	Description / Title / Event	
Fiscal Year 2002 (continued)		
Tech Memos (continued)	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)	
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, <i>Texas Transportation Researcher</i> , Vol. 37, No. 2	
Unpublished	Summary of Updates to the HOV and Park-and-Ride Facilities Design Guides by the AASHTO	
Papers	Subcommittee on Design, 2002 TRB Annual Meeting	
Presentations	Developing Managed Lanes, 2000 TxDOT Short Course	
	Operating Freeways with Managed Lanes, RMC 4 Meeting, June 2001	
	Operating Freeways with Managed Lanes, 2001 PMC Meeting, August 2001	
Semiannual	Research Supervisor Semiannual Progress Report – February 2001	
Reports	Research Supervisor Semiannual Progress Report – August 2001	
Status	Monthly Status Report – May 2001	
Reports	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: COMPLETED WORK

As a concise review of the status of the project, the following sections provide a summary of completed work to date. They are organized by task and related activities critical to the successful completion of the project.

During the first year of work, the project team undertook several tasks that set the tone for the entire effort. These tasks included establishing a definition of managed lanes, reviewing current literature in the area of managed lanes, establishing a glossary of terms, and hosting a managed lanes symposium for key stakeholders across Texas. During the second year of work, researchers completed work on the analysis of operations, concept marketing, geometric design, legislation, funding and financing, enforcement, and potential revisions to the TxDOT Traffic Operations Manual. The following sections provide a summary of the completed work and key findings for each task.

DEFINITION OF MANAGED LANES

At the onset of the project, the project director and the program coordinator wanted to agree upon a definition for managed lanes. This agreement established a definition that would serve 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 highlights key managed lane 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 by-pass lanes, dual facilities, and lane restrictions. Furthermore, the review brings 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 create an overall framework for the research planned for the project. They identify the operational strategies available to agencies and draw 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 in Report 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 the reader 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 the Austin TxDOT district as part of its HOV planning work and from a pricing glossary under development by the TRB pricing subcommittee. This glossary serves as a framework upon which researchers will base future efforts. Appendix B of Report 4160-2: *Year 1 Annual*

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Report of Progress: Operating Freeways with Managed Lanes contains the complete list of terms related to managed lanes (1).

MANAGED LANES SYMPOSIUM

As part of this project, the research team organized a managed lanes symposium to begin generating a dialogue between all potential partners and to provide insight into the concerns of those partners regarding operation of managed lanes. The research team hoped that a symposium would 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 TxDOT-sponsored 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. Attendees gained insight from experts around the country, who provided current thinking about managed lane operations. The complete proceedings of the symposium are contained in Report 4160-1: *Managed Lanes Symposium: Conference Proceedings (2)*.

ANALYSIS OF OPERATIONAL SCENARIOS BASED ON USER GROUP

As discussed previously, managed lanes are a complex issue. They incorporate several operational strategies that have unique characteristics. Thus, one of the research team's initial tasks was to analyze the various operational strategies available for managed lanes based on the user group to demonstrate the impacts of those strategies on design and traffic operations. The charge was to evaluate factors such as access design, access spacing, and geometric design to provide insight into such key factors as signing, delineation, and traveler information needs. The exercise of testing "what-if" scenarios can identify key features that agencies must consider with such facilities.

The purpose of this task was to demonstrate the impacts of alternative operating strategies on design and traffic operations considerations for managed lanes. 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.

Project Effort

Researchers selected the VISSIM model from among several traffic models capable of performing detailed modeling of managed lanes within freeway corridors. They then created a VISSIM model of the Katy Freeway corridor in Houston, Texas, 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 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.

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

Results

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 heavy vehicles in the vehicle stream have a more pronounced effect at shorter weaving distances. Freeway operation tended to stabilize at weaving distances greater than 3000 ft for medium volume levels and 3500 to 4000 ft for high freeway volume levels. When an intermediate ramp was located between the freeway and managed lane entrances, operation stabilized at weaving distances greater than 3500 ft for moderate volumes and 4000 ft for high volumes.

For freeway weaving across three lanes between a left-side managed lane exit and a rightside freeway exit ramp, modeling indicates that weaving and non-weaving freeway operations tend to stabilize at weaving distances greater than 3000 ft for medium volumes and 3500 ft 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 nonweaving flow stabilized for a four-lane weaving section at distances greater than 3000 ft.

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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 more substantial than the impact of bus percentage. Again, researchers expected such results, as the truck vehicle class is both larger and slower to accelerate/decelerate than buses.

Conclusions and Recommendations

The following list summarizes recommendations of the managed lanes modeling effort:

- 1. Standard analysis techniques, especially the Highway Capacity Manual (HCM) and Highway Capacity Software (HCS), are appropriate for isolated entrance, exit ramp, and one-sided weaving section analysis where these features must be studied 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.
- 2. 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 lane design guidelines specify either minimum (500 ft) and desirable (1000 ft) weaving distances per lane, or a preferred minimum distance (2500 ft) 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. Researchers developed a recommended weaving distance application table for anticipated conditions in the design year (see Table 3-1). The managed facility designer has the option of:

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

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	e for freeway vehicle mixes with up to	10% heavy vehicles;
higher percentages	of heavy vehicles will require incr	reasing the per-lane weaving distance.	The value used
should be based on	engineering judgment, though a n	naximum of an additional 250 ft per la	ne is suggested.

Table 3-1. Weaving Distances for Managed Lane Cross-Freeway Maneuvers.

- 4. For general managed lane planning purposes, the recommended minimum and desirable distances between a freeway entrance/exit ramp and a managed lanes entrance/exit are 2500 ft and 4000 ft, 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 ft of cross-freeway weaving distance is appropriate.
- Under moderate volume freeway conditions (i.e., LOS C or D), a maximum weaving volume of 450 vehicles per hour is recommended 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, vehicles need a transition distance of 1 mile 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 that the given value be increased. Note that these distances are the required transition distances once drivers have already determined whether or not they are candidates for the managed facility. Driver perception and decision distance values given here should determine sign location. Also note that the transition distance values given here provide sufficient upstream warning so that mainlane speeds are not significantly impacted by the selective separation of weaving vehicles; if lesser transition distances are used, mainlane and weaving vehicle speed will be reduced. Report 4160-4: *Managed Lanes – Traffic Modeling (3)* contains the complete results of this research task.

CONCEPT MARKETING STRATEGY

The success of a managed lanes facility relies in part on successful marketing on the part of the operating agencies. The goal of this marketing effort is to build understanding, relationships, and constituencies for managed lanes. To facilitate this task, the task team formed a technical advisory committee, which provided useful feedback. The committee consisted of public information officers from key TxDOT districts with managed lanes projects under development and directors of community relations from Dallas Area Rapid Transit (DART) and Metropolitan Transit Authority of Harris County, Texas (METRO). Under this task, researchers identified broad concept marketing strategies that defined the most effective approaches for

communicating and building consensus for managed lanes based on corridor and community goals. The team addressed several issues, including:

- determining public perception,
- identifying and communicating with stakeholder and special interest groups,
- communication techniques, and
- media relations.

The team then conducted a literature review that targeted various agencies around the country and their efforts to communicate the concept of managed lanes to the general public. The research documented different approaches, key messages, success factors, and lessons learned.

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 4160-5 (4) and 4160-6 (5). The team also published a position paper for a media audience (6) and a position paper for a policy-maker audience (7) 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 (*8*, *9*) were distributed to elected officials, boards and commission members, executives of public agencies, TxDOT personnel, cities, counties, transit authorities, and metropolitan planning organizations (MPOs), as well as to newspaper editorial boards, television and radio news directors, and magazine editors.

GEOMETRIC DESIGN RECOMMENDATIONS

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 (10)* and the Texas *Roadway Design Manual (11)*. A review of state design manuals demonstrated 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. The manuals provide general guidelines (900 to 1000 ft or 300 m); however, these

guidelines are not sensitive to the expected ramp volume, the anticipated destination of the ramp vehicles (e.g., the next exit ramp or a downstream entrance to a managed lane facility), or the number of lanes on the freeway. Work completed as part of TxDOT Project 0-4160, specifically the task on the analysis of operational scenarios based on user group, provided recommendations for spacing needs for cross-freeway weaving (e.g., between a right-side entrance ramp and a downstream left-side exit ramp to a managed lane facility) (*3*).

Research conducted under the geometric design task found that designers should consider a direct connect ramp between a generator and the managed lane facility when 400 veh/hr is anticipated to access the managed lanes. If a more conservative approach to preserving freeway performance is desired, then a direct connect ramp should be considered at 275 veh/hr (which reflects the value when the lowest speeds on the simulated corridor for the scenarios examined were at 45 mph or less).

The New Jersey Turnpike has two separate roadways in each direction of travel with each roadway having its own exit and entrance ramps. The "dual-dual" roadway improves operations and safety by separating heavy vehicles from light vehicles and increases capacity (heavy vehicles are only permitted on the outer roadway). It also increases flexibility for managing incidents as drivers can be directed to the roadway without incident through the use of changeable message signs. Available crash information showed lower crash rates for the dual-dual portion as compared to segments of the Turnpike without separate roadways (between 26 and 61 percent for 1994 to 1998). The dual-dual design used on a portion of the New Jersey Turnpike has significant operational and safety benefits. These benefits need to be quantified and a benefit-cost evaluation needs to be performed to determine if this approach is feasible within Texas. If the approach is feasible, research should determine the conditions when the design should be considered.

Recent literature on ramp design has focused on ramp design speed and truck performance. The current process allows for as much as a 50 percent reduction in design speed from a freeway to a ramp. Research has shown that the use of these minimum values of design speed provides little to no margin for error for large and/or heavily loaded trucks. The use of such large reduction can also impact operating speeds as a vehicle moves from one facility to another. To maintain high performance for the managed lanes facilities, the design speed selected for the ramps must consider the anticipated speeds of the vehicles entering the ramp, the

desired speed of the vehicles on the ramp, and the speeds of the vehicles the ramp vehicles will encounter when they are attempting to merge. A design speed less than the anticipated or desired operating speed will affect the performance of the managed lanes. If trucks are a primary vehicle type for the facility, they need to be explicitly considered during the selection of the design features for both the ramp and the managed lanes as well as the signing to be used. Report 4160-10: *Managed Lane Ramp and Roadway Design Issues (12)* contains the complete results of this research task.

IDENTIFY STATE AND FEDERAL LEGISLATIVE CHANGES OR REQUIREMENTS NEEDED

Transportation professionals are currently considering the managed lane concept on major freeway projects in Texas cities. The term "managed lanes" encompasses a variety of facility types, including HOV lanes, HOT lanes, single-occupancy vehicle (SOV) express lanes, special-use lanes, and truck lanes. The premise of the managed lanes concept is to increase freeway efficiency and provide free-flow operations for certain freeway users by packaging various operational and design strategies. The strategies deployed offer the flexibility of adjustment to match changing corridor and regional goals. The objective of this task was to assess the federal and state legislative needs necessary for Texas to successfully implement the various types of managed lane facilities across the state. Numerous federal and state laws govern the operations of these facilities in Texas. However, some gaps exist that prevent TxDOT and other operational agencies from having the complete arsenal of options available to design, operate, and enforce managed lanes under a variety of control scenarios and to make operational and eligibility changes over time as conditions change. At the federal level, the Federal Highway Administration (FHWA) fails to provide permanence to HOT lanes. At the state level, several gaps exist. The researchers recommend the following changes to remedy these gaps:

- define managed lanes as an operational concept in Texas and authorize entities to develop these facilities for congestion mitigation purposes,
- allow entities operational flexibility with managed lane facilities,
- authorize entities to develop exclusive lane facilities for congestion mitigation purposes,

- authorize TxDOT to establish lane restrictions for congestion mitigation purposes and remove the time-of-day limitation on the current municipal authorization for this strategy, and
- make unlawful violations in any managed lane facility in Texas punishable by fine.

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. Several of the recommendations were incorporated into Texas HB 1208, which Governor Perry signed into law on June 20, 2003. The complete results of this research task are contained in Report 4160-8: *State and Federal Legislative Issues for Managed Lanes (13)*.

FUNDING AND FINANCING OF MANAGED LANES

Numerous innovative financing approaches may be applicable to managed lanes, each with a unique set of considerations related to capital costs and operating expenses. As part of this task, the research team explored available financing options and the applicability of each as they relate to financing managed lanes projects. The research identified several alternative-financing methods from the traditional pay-as-you-go method that may be utilized for a managed lanes project. The research also identified gaps in current state and federal legislation where changes could result in more financially feasible projects.

The task team assembled an advisory committee of personnel from TxDOT, Harris County Toll Road Authority (HCTRA), North Texas Tollway Authority (NTTA), Texas Turnpike Authority (TTA), FHWA, and the private sector as well as project managers involved in developing managed lanes projects. The committee provided input on the scope of the task and valuable review comments during the research.

The complete research report (14) includes an appendix that highlights operating managed lanes projects around the country. The case studies presented in the appendix document the financial plans of several projects that are in operation or are being developed.

ENFORCEMENT PROCEDURES AND DESIGN

The purpose of the enforcement task was to outline enforcement procedures and design elements of managed lanes. These vary depending on user groups, operational parameters, and application of available technologies. The research report for this task (*15*) highlights several corridors operating with managed lanes that incorporate multiple combinations of enforcement procedures and designs. The intent of information provided is to give a comprehensive overview for the state-of-practice concerning managed lane enforcement while acknowledging the migration to increased automated enforcement. Key information provided in the task report includes the following:

- the role of enforcement on managed lanes,
- various strategies for enforcement,
- general enforcement information and procedures from various managed lane locations,
- incorporating enforcement in design,
- discussion of agencies and their responsibility of enforcing managed lanes at various locations around the country, and
- managed lane enforcement technology.

REVISIONS AND ADDITIONS TO THE TRAFFIC OPERATIONS MANUAL

The *Highway Operations* volume (*16*) of TxDOT's *Traffic Operations Manual* (*17*) 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 have ceased work on this task after TxDOT approved a modification requesting to eliminate 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* (18) and the *Guide for the Design of Park-and-Ride Facilities* (19). 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* (20), the TxDOT-sponsored *Guidance for Planning, Operating, and Designing Managed Lane Facilities in Texas* (21), the previous AASHTO HOV and park-and-ride guides (18, 19), and the AASHTO *Green Book* (10). The *Park-and-Ride Planning and Design Guidelines* (22) 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 upon 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 it is anticipated that AASHTO will publish the guides in the fall of 2004.

IDENTIFYING TRAVELER INFORMATION AND DECISION-MAKING NEEDS

In this task, researchers identified the interrelationships that exist between various managed lane design options, operational strategy combinations, and information needs for travelers wishing to enter or exit a managed lane facility. Researchers utilized the draft signing and marking plans of the Houston Katy Managed Lane project as a case study to more fully understand, characterize, and prioritize the difficulties that arise in meeting traveler information needs within the context of a particular managed lane configuration. Researchers conducted focus group studies in Dallas, Houston, and San Antonio to determine what information drivers believe they need and how well they understand current and proposed message formats for managed lane operations. The research team also developed a conceptualized driver decision-making model to help managed lane designers understand the type of information that drivers need in order to make informed decisions about whether or not to use the managed lane facility.

As drivers traverse a roadway again and again, they become familiar with the signs and information that are required to properly travel the managed lane or general-purpose lanes in that area. Because the needs of drivers change over time, and each driver has a different threshold of information processing, the designers of the information dissemination for a managed lane facility need to determine which members of the driving population they are targeting (or can target) to use 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 need to be presented.

Determination of who the target audience really is (familiar, semi-familiar, or unfamiliar) can help determine how much information must be presented within the managed lane corridor regarding the managed lane. Additionally, if the target audience can be defined specifically,

such as toll users who have electronic transponders, other options for information dissemination become available. The identification of 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.

Recommendations are made for further research into which types of information could be moved off of the roadway and presented in other formats, such as the Internet or highway advisory radios. The researchers documented the results of this task in Report 0-4160-13 (23) that was published during fiscal year 2004.

DEVELOPING RECOMMENDATIONS FOR TRAFFIC CONTROL DEVICES FOR MANAGED LANES

Perhaps the most critical design element of managed lanes outside of the physical facility is the user information system. This system, consisting of traffic control devices, is the manner in which the facility provides key operational information to travelers. Delivered in the form of traffic signs, pavement markings, and general delineation, this system provides appropriate information to travelers at the correct time and in a format easily understood. If the user information system does its job correctly, travelers can make informed decisions regarding their use of the managed lane facility and can navigate into, through, and out of the facility in a safe and efficient manner. Obviously, the challenges associated with providing this information are complex given the varied information and decision-making needs that will be identified in the user information task.

This task reviewed domestic and international standards and practices for traffic control devices for managed lanes facilities. Researchers completed this task in close cooperation with the task addressing traveler information needs. They found few standards, but they provide limited recommendations based on best practices in Report 0-4160-16 (*24*). That report also identifies areas for future research in this area.

The research team thoroughly reviewed the U.S. *Manual on Uniform Traffic Control Devices* (MUTCD) and the Texas MUTCD regarding preferential use lanes (the term used in the MUTCD). The majority of the standards pertain to lanes restricted to high-occupancy vehicles, buses, and trucks. Researchers found no standards that pertain directly to toll facilities. They also sought past research on the design and effectiveness of traffic control devices for managed

lanes, but again, they found little due to the relatively recent creation of the actively managed lane. Research for traffic control devices for high-occupancy vehicle lanes provides the closest analog to the Texas managed lane concept. Examples of current practice on managed lanes facilities in Europe and the United States were collected and organized into the following categories:

- sign color and banners,
- symbols,
- terminology,
- sign placement,
- changeable message signs,
- lane control signals,
- lane line pavement markings, and
- horizontal signing.

Based on focus groups conducted as part of the traveler information task, researchers identified several key issues which should receive priority in future research and standards efforts in this area. First is the use of color coding to clearly identify signs related to managed lanes. Second is the need for consistent symbols to indicate allowed vehicles. Third is the use of the term EXIT to refer to the entrance to a managed lane facility. Drivers participating in the focus groups found this particularly confusing. Last is the desire on the part of drivers to have advance information about access points within the managed lane. Advanced distance/destination signs would address this issue.

DEVELOPING A FRAMEWORK FOR OPTIMUM INCIDENT MANAGEMENT

The purpose of this task was to identify incident management policies and procedures that are critical to facilities with managed lanes and provide 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, HCTRA, METRO, NTTA, and DART. The committee provided input on the development of the survey instrument and commentary on the findings from the survey recipients' responses.

Over 80 survey responses, and selected follow-up interviews, formed the basis for the framework of recommendations for incident management on facilities with managed lanes. 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. This effort addressed several issues, including:

- 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.

The research team will publish the report for this task next year and will include an overall description of the research undertaken and the findings and recommendations regarding incident management in managed lanes.

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 operation. These ongoing operations include management, enforcement, incident detection, revenue collection, enforcement, and more. Often, a managed lanes facility is cross-cutting, not only in the use of multiple operating concepts to achieve goals, 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?

Researchers conducted an extensive literature review and a survey of the profession to address these questions.

The literature review utilized multiple databases and search terms to encompass the concept of interoperability. Perhaps the most important finding of this task was the aspect of levels within the overall concept of interoperability. These three levels, agency, facility, and equipment, can provide more structure or definition to the identified interactions.

The literature review provided a basic breakdown, or matrix, of interoperability concerns as they apply to managed lanes. As an example, as shown in Table 3-2, enforcement is an activity that should be coordinated at an agency level. In particular, this points to the need to establish supporting similar enforcement policies across agencies, so that driver expectations are not violated between users of regular lanes, managed lanes, and any other special user group facilities, such as toll lanes.

	Agency	Facility	Equipment
Geometric Design	✓	\checkmark	
Operations	✓	✓	✓
Enforcement	✓		
Communications		✓	✓
Traffic Control Devices		✓	✓
Planning	✓		
Incident Management	✓	✓	
Legislation	✓		
Evaluation	✓		

The results of the literature review provided a solid basis for understanding the broad range of interoperability concerns. However, researchers understood that more in-depth knowledge could be obtained 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.

Researchers constructed a 24 question survey and put it online at the managed lanes website. They sent out notification of the survey via newsletters and email listservs to an estimated audience of more than 5300 professionals in the transportation industry. However, one should recognize that only a small percentage of the target audience has experience with managed lanes facilities and that researchers did not anticipate a significant response rate. 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 was a modification of the literature review matrix by allowing five levels of criticality to be assigned to each area. Researchers used a weighted average technique to determine the critical levels associated with each area. Table 3-3 shows the results.

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

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

In Table 3-3, the checkmark (\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 3-3 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 lead to inefficiencies in the overall system but will not result in a breakdown of the facilities in question.

Finally, the asterisk sign (*) represents those interactions which agencies should consider 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 the motorists.

Researchers will use the matrix shown in Table 3-3 to determine where interoperability concerns should be identified and discussed in the managed lanes manual. In particular, each section dealing with interoperability concerns will identify the need, scope, and options available for meeting the identified concern.

Finally, the results of both the literature and survey identified several topics or areas where additional research is still needed. Some of these topics include:

- 511 interoperability,
- shifting the transit ridership model,
- coordination of public/private funding,
- environmental impacts of managed lanes, and
- aesthetic concerns of managed lanes.

The research team will publish the report for this task next year, which will include an overall description of the research undertaken and the findings and recommendations regarding interoperability and managed lanes.

CHAPTER 4: WORK UNDER WAY

The following sections provide a brief overview of tasks that are under way but will be completed in subsequent years. They outline milestones and progress throughout the course of the year and highlight key issues or interim findings that were of critical importance.

DECISION MATRIX FOR CONSIDERING DESIGN AND OPERATIONAL OPTIONS BASED ON A PARTICULAR USER GROUP(S)

The type of users authorized to use a managed lane facility will play a critical role in the feasibility, design, and operation of a managed facility. A matrix of possible operating strategies for various eligible user groups will correlate eligibility decisions with realistic considerations for planning, designing, and operating a managed lane facility. Researchers are exploring factors related to operational flexibility and time-of-day variations. They update the matrix as each task of the project is completed. Each task provides critical information in creating a comprehensive matrix containing all of the information necessary to make informed decisions regarding the design and operation of managed lane facilities. The matrix forms the backbone of the final project product: the *Managed Lanes Manual*.

This task is an ongoing process throughout the research effort to develop a framework for supporting decisions related to the development of managed lane projects. The research team incorporates research results into the framework over time. Furthermore, the process of developing the framework itself has helped identify gaps in the knowledge base that the research project can address.

Currently, researchers are adapting logical and statistical approaches to knowledge representation toward the goal of constructing a geometric model of the managed lanes planning process. Such a model locates the various planning objectives and operating strategies in terms of their mutual similarities/appropriateness to one another. This type of model may be used to map regions corresponding to particular operating strategies in terms of the planning objectives and associated corridor characteristics/criteria commonly associated with those strategies.

Researchers are developing a preliminary associative map of managed lanes objectives and operating strategies by applying nonmetric multidimensional scaling techniques to consensus associative groupings of objectives and strategies. The idea is to represent the various objectives, operating strategies, and corridor constraints as a map, where distance between points

denotes the degree of association between them. The input data for such a process are derived from polling or survey data, where knowledgeable professionals are asked to group the various objectives and strategies. Each group must contain at least two objectives, and the groups are mutually exclusive; i.e., each objective can only be included in one group. Once these objectives are grouped according to how similar or related they are to one another, a geometric mapping can be performed. The mapping process translates the similarity of objectives would appear close to one another, while two extremely different objectives would have a sizeable distance between them. This configuration reflects the "hidden structure" in the data, and often makes the data much easier to comprehend. In this case, a geometric mapping arises from the latent criteria used by the survey subjects in their grouping choices.

Concurrent with this effort, the research team is utilizing sketch planning to incorporate corridor characteristics and related corridor performance criteria into the managed lanes planning model. Briefly, sketch planning is a technique for diagrammatically displaying the constraints and input criteria in a planning or design process.

Figure 4-1 represents the conceptual decision-making framework which depicts the sequential elements considered in implementing a managed lanes project. Features of the diagram include the following:

- incorporation of financial goals, particularly those involving revenue generation, into the general policy framework;
- objective-based decision making in determining potential user groups and the use of pricing for demand management and/or revenue generation;
- the combination of vehicle user groups and operating strategy as the basis for determining design parameters for the project;
- the involvement of other agencies in the process, as well as multiple opportunities for public input;
- a strong link between design and operations in the development of schematic design; and
- a re-evaluation process if expected performance does not meet the desired outcome.



Figure 4-1. Conceptual Design Framework.

DEVELOPING A MANAGED LANES MANUAL

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 team has developed the initial four chapters of a *Managed Lanes Manual*. These chapters, which include a guide to the manual, an introduction to managed lanes, planning, and design, are in draft form. 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. Detailed outlines for the initial four chapters and the titles of the remaining chapters follow.

1. Guide to the Managed Lanes Manual

- 1. Overview
- 2. Overall Conceptual Framework
- 3. Chapters at a Glance
- 4. Chapter Format

2. Introduction to Managed Lanes

- 1. Overview
- 2. Definition of Managed Lanes
 - TxDOT Definition
 - Focus on Flexibility
- 3. Managed Lanes Operational Strategies
 - Variety of Terms
 - Managed Lane Operational Strategies
- 4. High-Occupancy Vehicle Lanes
 - Separated Two-Way HOV Lanes
 - Concurrent-Flow HOV Lanes
 - Contraflow HOV Lanes
 - Expectations and Constraints
- 5. Value-Price Lanes and High-Occupancy Toll Lanes
- 6. Exclusive Lanes
 - Exclusive Busways
 - Exclusive Truck Lanes
- 7. Separation/Bypass Lanes
- 8. Lane Restrictions
- 9. Dual Facilities
- 10. References

3. Managed Lanes Facility Planning

- 1. Overview
- 2. Goals and Objectives
 - Mobility Goals
 - Community Goals
 - Financial Goals
- 3. Data Collection
 - Corridor Conditions
 - Policy Issues
 - Project Objectives and Performance Measures
- 4. Selection of Operating Strategy and User Groups
- 5. Institutional Partnerships and Agency Roles
- 6. Public Input and Outreach
 - Public Input
 - Public Outreach

4. Managed Lanes Facility Design

- 1. Overview
- 2. Geometric Considerations for Managed Lanes Facilities
 - Overview
 - Design Vehicle
 - Design Speed
 - Horizontal Clearance
 - Vertical Clearance
 - Stopping Sight Distance
 - Superelevation
 - Cross Slope
 - Minimum Turning Radius
 - Horizontal Curvature
 - Vertical Curvature
 - Gradients
 - Summary of Managed Lane Mainland Design Guidelines
- 3. Cross Sections for Managed Lanes Facilities
 - Design Considerations for Exclusive Freeway Managed Lanes
 - Design Considerations for Concurrent-Flow Managed Lane Facilities
 - Design Considerations for Freeway Contraflow Managed Lanes
- 4. Design Considerations for Terminal and Access Treatments
 - Overview
 - Selecting Ramp Type
 - Design Speed
 - Direct Access Ramps
 - Managed-Lane-to-Managed-Lane Connection
 - At-Grade Access
 - Slip Ramps

- Design Considerations for Bypass Lanes at Ramp Meters
- 5. Enforcement
- 6. Incident Management
- 7. Construction, Interim, and Special Operations
- 8. Monitoring and Evaluation
- 9. Administration and Staffing

CHAPTER 5: YEAR 5 EFFORTS

The following section outlines the tasks that will begin during year 4 of the project. In particular, they highlight key results researchers expect from these tasks.

PROVIDE RECOMMENDATIONS FOR STAFFING AND TRAINING NEEDS

Managed lane facilities present new challenges to the agency or agencies responsible for their operation. The potential complexities associated with user groups and operational options will require agencies to have an appropriate number of qualified staff to ensure adequate oversight of operations and to ensure satisfactory customer service to the users. Thus, this task will identify those staffing needs related to operational options and specific training that might be required to ensure those staff are fully prepared to perform their duties to the satisfaction of both the agency and the customer. Researchers will consider the potential for complex operational scenarios and use of advanced technologies in these recommendations. Other issues they will address will be the roles of job positions with the framework of managed lanes, the competencies required of those positions, and accessibility to appropriate training, education, and technical assistance to ensure training needs are met.

DEVELOP STRATEGIES FOR INTERIM MANAGED LANE USE DURING CONSTRUCTION, SPECIAL EVENTS, AND EMERGENCIES

While the overall concept of this project is to address the operational issues associated with completed managed lane facilities, there is the potential application of these strategies to the provision of managed lanes during special situations. Such situations might include lengthy construction and reconstruction projects, special events, or such emergencies as natural disaster evacuations. Thus, this task will develop strategies for providing managed lanes to various user groups during these situations based on the needs of the users and the mobility policies of the agency and community at large.

DEVELOP RECOMMENDATIONS FOR MANAGED LANES EVALUATION AND MONITORING.

Evaluation and monitoring are important yet overlooked aspects of highway improvement projects. Post-project monitoring is a particularly critical component of projects that have an operational emphasis, such as managed lanes. In order to maintain a high level of service and free-flow speeds for the users of the facility – for transit, other high-occupancy vehicles, and paying customers – conditions must be monitored and evaluated, and tolls adjusted accordingly.

Ideally, threshold values for typical measures of effectiveness for common managed lane objectives should be defined, although the current practical experience is far too limited to define general threshold values. A guideline on the length of time that a managed lane should be operational before results can be accurately assessed is also needed. This is especially important for privately operated ventures that are seeking a rate of return on investment. As more projects move forward and the experience base increases, additional guidelines on project evaluation and monitoring can be developed.

CHAPTER 6: FINAL REMARKS

The first year of the managed lanes project was critical to the future success of the project and provided a strong foundation for effective and comprehensive work researchers will undertake in subsequent years. Initially, the research team formalized the various oversight committees necessary for the complex management of the project. These committees help build support and garner input and priority needs from TxDOT project managers, staff, and other stakeholders in the managed lane arena. The research team also worked with TxDOT to define managed lanes for the purpose of the project. This definition serves as the official definition for the entire TxDOT organization, reflecting the flexibility and complexity of the managed lanes concept. Using this definition as a foundation, the research team then identified a vision for managed lanes research and specific objectives for this particular project, both of which help guide the project and ensure that TxDOT's needs are met along the way.

The literature review, which reviews operational strategies and highlights key issues regarding the implementation of managed lanes, created an overall framework for the research planned in the project. Researchers will rely on this document and the companion glossary of terms to provide insight into specific areas of concern for various operational issues they investigate. The results from the managed lanes symposium also aided the researchers in directing the project so that they address the major issues and concerns of stakeholders over the course of the project.

During the second year, researchers completed numerous tasks, including the analysis of operational scenarios based on user groups, concept marketing, legislative needs, funding and financing, geometric design, and enforcement. The team also continued to work on the development of a decision matrix for considering design and operational options, and assisting with the revision of the AASHTO manuals. The team approach to managing the project, which includes bi-monthly task leader meetings, helps researchers identify gaps in the knowledge, coordinate their tasks with those of others, and ensure that they are effective in their research.

During the third and fourth years, researchers assessed the subjects of traveler information, traffic control devices, and incident management. They also undertook the assessment of interoperability needs pertaining to infrastructure and technology. Each of these tasks produced usable results that provided additional resource material for the *Managed Lanes Manual*. The research team developed separate research reports for each task.

During the final year of the project, researchers will finalize the decision matrix, complete development of the managed lanes manual, and wrap up the research by addressing interim use, staffing, and evaluation and monitoring. As with previous tasks, researchers will take a team approach to completing their work, ensuring efforts are not duplicated and the results are comprehensive and cohesive.

The research team looks forward to another productive project year and the success of finding more pieces of the complex puzzle of managed lanes.

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