**Technical Report Documentation Page**

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| FHWA/TX-05/0-4160-18 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| INTEROPERABILITY ISSUES ON MANAGED LANES FACILITIES | September 2004 |
| | 6. Performing Organization Code |

| 7. Author(s) | 8. Performing Organization Report No. |
|---|---|
| Robert E. Brydia and Stephen Song | Report 0-4160-18 |

| 9. Performing Organization Name and Address | 10. Work Unit No. (TRAIS) |
|---|---|
| Texas Transportation Institute<br>The Texas A&M University System<br>College Station, Texas 77843-3135 | 11. Contract or Grant No.<br>Project No. 0-4160 |

| 12. Sponsoring Agency Name and Address | 13. Technical Report: |
|---|---|
| Texas Department of Transportation<br>Research and Technology Implementation Office<br>P. O. Box 5080<br>Austin, Texas 78763-5080 | September 2003 - August 2004 |
| | 14. Sponsoring Agency Code |

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Operating Freeways with Managed Lanes

16. Abstract

Interoperability is the ability of a system to use the parts, information, or equipment of another system. In the case of a managed lane, the facility must act in concert with the adjacent infrastructure to accomplish mobility goals. Using a literature review and an extensive survey of the profession, researchers compiled the critical interoperability concerns for a managed lanes facility so that planners, designers, and operators can focus on these interactions and create a successful facility.

A key concept of the research findings is that interoperability actually exists at multiple levels; agency, facility, and equipment. Each of the seven critical areas (planning, geometric design, traffic control devices, operations, incident management, surveillance and monitoring, and communications) have interoperability concerns at one or more of these levels.

This report details the results of the literature review, the online survey of the profession, and culminates with recommended text for inclusion in the managed lanes manual for the Texas Department of Transportation.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Managed Lane, Interoperability, Coordination. | No restrictions. This document is available to the public through NTIS:<br>National Technical Information Service<br>Springfield, Virginia 22161<br>http://www.ntis.gov |

| 19. Security Classif.(of this report) | 20. Security Classif.(of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 76 | |

# INTEROPERABILITY ISSUES ON MANAGED LANES FACILITIES

by

Robert E. Brydia
Associate Research Scientist
Texas Transportation Institute

and

Stephen Song
Undergraduate Student Fellow
Texas Transportation Institute

Report 4160-18
Project Number 0-4160
Project Title: Operating Freeways with Managed Lanes

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

September 2004

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

# DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The researcher in charge was Robert E. Brydia.

# ACKNOWLEDGMENTS

The authors gratefully acknowledge the contributions of numerous persons who made the successful completion of this report possible. Thanks are extended to the Texas Transportation Institute (TTI) Advisory Team: Dennis Christiansen, Katie Turnbull, Ed Seymour, Bill Stockton, and Tim Lomax. In addition, the research discussed herein could not have been accomplished without the efforts of the following TTI individuals: Bradley Hoover, Chris Giddens, Hong Yu, and Diane Fischer.

It should be noted that the researchers have relied upon critical input from individuals within the transportation community during the survey aspect of the research. While these individuals are anonymous, their expertise, input, and time is greatly appreciated.

Special thanks are extended to TxDOT and FHWA for support of this research project. The researchers also acknowledge the following members of the project monitoring committee, both past and present, for their leadership, time, efforts, and contributions:

**Program Coordinator**

- Gary K. Trietsch, P.E., Houston District, TxDOT

**Project Director**

- Carlos Lopez, P.E., Traffic Operations Division, TxDOT

**Current Technical Panel**

- Charles H. Berry, P.E., El Paso District, TxDOT
- David B. Casteel, P.E., San Antonio District, TxDOT
- Maribel P. Chavez, P.E., Fort Worth District, TxDOT
- Robert B. Daigh, P.E., Austin District, TxDOT
- Clint Jumper, P.E., Traffic Operations Division, TxDOT
- James Kratz, P.E., Traffic Operations Division, TxDOT
- William L. Hale, P.E., Dallas District, TxDOT
- Mark A. Marek, P.E., Design Division, TxDOT
- Mary M. Owen, P.E., Tyler District, TxDOT

- James Randall, Transportation Planning and Programming Division, TxDOT
- Carol Rawson, P.E., Traffic Operations Division, TxDOT
- Phillip Russell, P.E., Texas Turnpike Authority, TxDOT
- Amadeo Saenz, Jr., P.E., Assistant Executive Director for Engineering Operations, TxDOT
- Richard Skopik, P.E., Waco District, TxDOT

**RTI Engineer**

- Wade Odell, P.E., Research and Technology Implementation Office, TxDOT

**Previous Technical Panel Members**

- Michael W. Behrens, P.E., Executive Director, TxDOT
- Ken Bohuslav, P.E., Design Division, TxDOT (Retired)
- William Garbade, P.E., Austin District, TxDOT (Retired)
- John Kelly, P.E., San Antonio District, TxDOT (Retired)
- Alvin Luedecke, Jr., P.E., Transportation Planning and Programming Division, TxDOT (Retired)
- Jay Nelson, P.E., Dallas District, TxDOT (Retired)
- Steven E. Simmons, P.E., Deputy Executive Director, TxDOT
- Robert Wilson, P.E., Design Division, TxDOT (Retired)

# TABLE OF CONTENTS

**Page**

# LIST OF FIGURES

**Page**

# LIST OF TABLES

**Page**

# CHAPTER 1:
# INTEROPERABILITY AND MANAGED LANES

## INTRODUCTION

Bringing a managed lanes facility to completion is a complex process of planning, design, and daily operation. Once complete, these on-going operations may include management, enforcement, incident detection, revenue collection, maintenance, 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 relationships all point to a level of interaction heretofore unseen for most roadways. In essence and indeed in practice, while it may serve special user groups, a managed lane becomes an integral part of the transportation system. A typical statement is that the facility must be interoperable with other facilities in the transportation system.

## INTEROPERABILITY

What is interoperability? At the lowest level, the term basically means that certain things should work together. As an example, a videotape recorded in one brand of machine should play in a machine of another brand, as long as the format is the same. The machines would then be interoperable. As another example, this report can be read on any computer that uses the same software that was used to create it. In fact, this level of interoperability goes beyond the use of the same software. Because multiple programs understand the underlying format of the electronic file, this report can actually be read and edited in any number of software applications. The data format is the same, which allows the applications to work together.

Within the application of managed lanes, many items should work together. Ramps must connect the mainline facility with the managed lanes. Motorists must be able to get information about how to get on the managed lanes, where they are allowed, at what times, and how much it will cost. Police and emergency services must plan for enforcement and emergency operations that will utilize both the mainline and managed lanes. The summation of all of these elements (and more) across all aspects of the transportation system should work together to support the traffic operations.

In the dictionary, interoperability is defined as "the ability of a system to use the parts or equipment of another system (*1*)." Within the application of managed lanes, it is entirely` possible that interoperability could also refer to the exchange of information to other systems. Therefore, the definition that governs this research can best be expressed as 'the ability of a system to use the parts, information, or equipment of another system.'

## RESEARCH QUESTIONS

As a relatively new concept in transportation, and most especially a managed lanes facility, the research base for examining interoperability concerns does not exist. Due to this fact, the questions that need to be answered are basic, so that a foundation for this knowledge can be established. Within the application of managed lanes, several questions relate to interoperability. They include:

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

## RESEARCH GOAL

The goal of this research is two-fold:

1) Develop a matrix illustrating where interoperability concerns are most critical to address in a managed lanes facility.
2) Develop draft text for inclusion in the managed lanes manual, addressing the interoperability concerns represented in the matrix.

Note that the goal of this task is not to develop a stand-alone chapter of the managed lanes manual, but rather to supplement the other existing chapters with additional information on addressing interoperability concerns

## RESEARCH APPROACH

There were three steps in the research approach to this task. The first step was the conduct of the literature review. The objective of the literature review was to identify the major

areas of concern with regard to interoperability. In addition, the literature formed the basis for developing detailed questions for step two of the task.

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

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

# CHAPTER 2:
# LITERATURE REVIEW

## CONDUCT OF LITERATURE REVIEW

Because the investigation of interoperability issues related to managed lanes is a relatively new concept, the body of literature that would match those specific key words is relatively sparse. In order to obtain a wider perspective, the searches used a broad range of search terms. As an example, the concept of interoperability could also be expressed by:

- interoperable,
- inter-agency coordination,
- agency coordination,
- regional coordination,
- corridor coordination,
- inter-agency planning,
- regional planning,
- corridor planning,
- data fusion, or
- data sharing.

The concept of a managed lane can also be referenced by such terms as:

- high-occupancy vehicle (HOV),
- high-occupancy toll (HOT), or
- diamond lanes.

In total, more than 50 combinations of key words were used to search the literature. The TRANSPORT and TRIS-ONLINE databases were searched as well as the Partners for Advanced Transit and highways (PATH) database from the University of California system. Each combination of key words or phrases was searched in each database.

With such a large number of terms used in the database searches, it was no surprise that the resulting number of hits was quite extensive. This resulted in the need to carefully review the abstract of each hit to determine if it was truly applicable to the topic of interoperability and

managed lanes. In the end, with more than 700 hits from the search parameters, a total of approximately 40 articles were secured for an in-depth reading and review.

## LITERATURE REVIEW FINDINGS

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

- agency,
- facility, and
- equipment.

These three levels, expressed in Figure 1, can essentially be used to provide more structure and definition to the identified interactions.

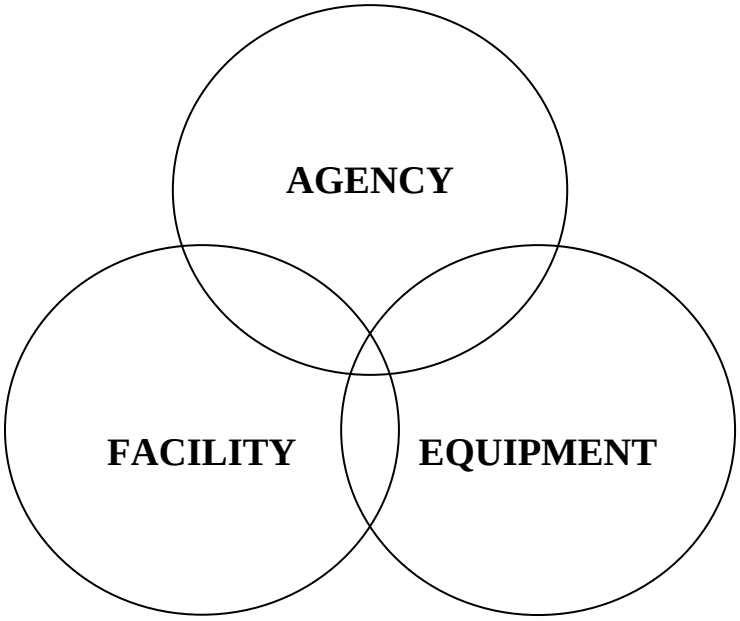



**Figure 1. Levels of Interoperability.**

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

In addition to the concept of levels, the literature also provided several points of information for consideration. These points include:

- There are differences between incident management in a managed lanes facility and a non-managed lanes facility (*2*).
- In some regions, the public does not seem to perceive tolling to be inequitable as long as there are other options (*3*).
- Various agencies should be able to communicate despite having different kinds of equipment (*4*).
- The existence of formal agreements among agencies is important (*5*).
- Managed lanes should not be developed separately from each other or from other infrastructure (*6*).
- The decisions of one agency (or facility) will impact other agencies (or facilities) (*5*).
- Evaluations are necessary to properly identify benefits and rewards (*7*).
- Seasonal effects should be considered, since large volumes of traffic may require a different operational plan (*8*).
- Tolls collected on managed lanes may be used to manage demand, and/or generate revenue, depending on the jurisdiction and the goals and objectives of the project (*3*).
- Plans should be scalable to accommodate agencies and facilities of different sizes (*6*).

- Due to privacy concerns, there is reluctance among government agencies to share certain information with the public (*9*).
- Interoperability requires both institutional agreements and adherence to common technological formats and standards. This allows for flexibility and advancements, while preserving the base investment used to develop systems and solutions (*10*).

## INITIAL INTEROPERABILITY MATRIX

The results of the literature review provided a solid basis for understanding not only the range of interoperability levels, but also some of the specific areas in which interoperability concerns were present. Table 1 presents the interoperability matrix that was created from the literature findings.

**Table 1. Matrix of Interoperability Concerns Developed from Literature Review.**

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

Note that this matrix was partially developed by inference, as there was no literature that directly supported each topic within the context of managed lanes. A typical example of this inference occurred in the literature dealing with communications. While there were no articles addressing communications interoperability for a managed lanes facility, there is a wealth of literature addressing the need for increased interoperability in communications systems. This is especially true within the context of emergency responders. Perhaps the most critical point of

communications interoperability is a need for different groups or agencies to have the ability to operate on the same frequency in the event of a shared response. The tragedy of 9/11 highlighted this need, as it is estimated that more than 170 New York City firefighters would have escaped the Twin Towers prior to the collapse if they had been able to hear the collapse warning that was broadcast on the police frequencies (*6*). Thus, by inference and application to the context of managed lanes, communications interoperability must take place at both the agency and equipment level. The agency level ensures that policies and support are in place to cooperate with other agencies and regional authorities for shared communications. The equipment level ensures that the purchase of radios and supporting infrastructure is compatible across the frequencies established by the agencies for common communications. Similar lines of reasoning were used for other areas of the table.

# CHAPTER 3:
# SURVEY OF THE PROFESSION

## SURVEY DESIGN

The purpose of developing the survey was to supplement the literature review with the knowledge and experience captured from the profession. This expertise served to highlight relevant issues as well as identify areas that require additional investigation.

The survey consisted of a total of 24 questions in the following eight general categories:

- identification of major interoperability issues,
- geometric design,
- operations,
- enforcement,
- communications/data exchange,
- incident management,
- maintenance, and
- conclusions.

In most cases, each individual section of the survey first asked a respondent to rank issues associated with the general topic, such as geometric design. This ranking served to identify and prioritize the critical issues within each topic area. In many cases, these rankings were also categorized across the three levels of interoperability identified from the literature review, namely, agency, facility, and equipment.

Each section also provided the respondent with the opportunity to add items into the list of items to be ranked, if they felt like an issue was missing. In addition to the ability to add issues and rank, each section provided the opportunity for the respondent to submit any additional comments relating to that particular topic are of the survey.

Figure 2 shows a sample page from the survey. The survey utilized standard Hypertext Markup Language (HTML), required no add-on components, and worked across standard browsers. The full text of the survey appears in the Appendix.

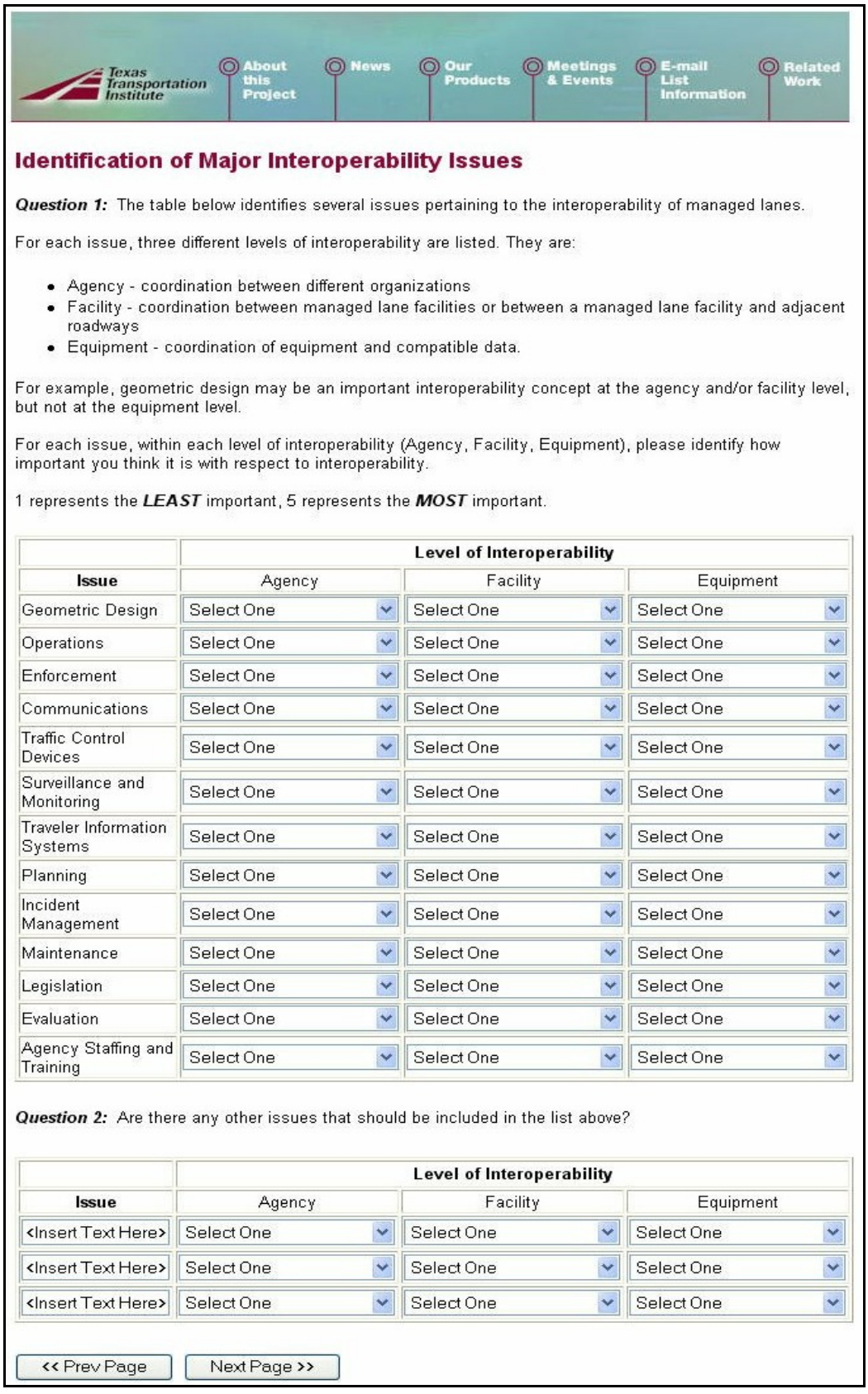



**Figure 2. Sample Page from Interoperability Survey.**

### Major Interoperability Issues

The first and perhaps most important section of the survey was the identification of major interoperability issues. In this section, respondents were asked to rank the importance of several issues, according to the three levels of interoperability (agency, facility, and equipment). Each ranking took place on a level of 1 through 5. The rating 1 represented "Least Important" and 5 represented "Most Important." In addition, respondents also had the capability to choose "Not Applicable" (N/A) for each ranking.

The research team investigated these 13 issues:

- geometric design,
- operations,
- enforcement,
- communications,
- traffic control devices,
- surveillance and monitoring,
- traveler information systems,
- planning,
- incident management,
- maintenance,
- legislation,
- evaluation, and
- agency staffing and training.

The basis for this list was the literature review conducted in the course of this research. Chapter 2 presents these results. In addition, the list was supplemented with other issues pertaining to managed lanes. Researchers were aware of these issues through project meetings as well as discussions with practitioners and other researchers.

### Geometric Design

The section pertaining to geometric design asked respondents about several issues, in particular, those pertaining to ramp, lane, and separation characteristics. From both the literature

and other tasks within the managed lanes project, these features are critical for geometric consideration. As with previous sections, respondents ranked their answers on a scale of 1 to 5, with an option for N/A.

**Operations**

Operations covers a diverse set of activities. The questions in this section presented several common activities to investigate their order of importance, in order to see where interoperability efforts should be focused. As part of the questions, the rankings were stratified by the level of coordination so that respondents could also indicate at what level interoperability efforts should primarily take place. For this section, these levels were defined as:

- metropolitan – coordination across the city,
- regional – coordination across the city and surrounding area,
- state – coordination across the entire state, and
- national – coordination across the United States.

Each ranking took place on a level of 1 through 5. Level 1 represented a rating of "Least Important" and 5 represented a rating of "Most Important." In addition, respondents also had the capability to choose "Not Applicable" (N/A) for each ranking.

**Enforcement**

The survey focused on three issues with regard to enforcement. In the first issue, the questions asked what agencies should be involved in setting enforcement policies. Due to the potential for a large number of partners in a managed lanes project, finding out who should be 'around the table' when discussing enforcement issues was thought to be a key concern.

In the second issue, the questions sought to determine what agency is best suited toward the actual implementation or enforcement of those policies. This question utilized a much smaller list but served to highlight the potential jurisdictional boundaries that enforcement activities must consider.

Finally, the third aspect of this section of the survey sought to identify which technologies respondents felt were most important to the enforcement process of a managed lanes facility.

As with the other sections, most rankings took place on a level of 1 through 5. Level 1 represented a rating of "Least Important" and 5 represented a rating of "Most Important." In addition, respondents also had the capability to choose "Not Applicable" (N/A) for each ranking. Some questions in this section had more restrictions on the response and would allow a respondent to pick only one answer from the list of possible responses.

**Communications/Data Exchange**

While the broad concept of sharing information sounds relatively benign, the actual exchange can be quite a task. Interoperability is an inherent issue in data communications, as data are always flowing from one point to another. Many times, the flow of information is also from one agency to another. For the purposes of this survey, the questions related to communications and data exchange focused at the higher levels. That is to say, rather than examining the issues associated at the protocols and applications level, the questions focused on the systems level, in order to determine what aspects of communications interoperability were the most critical.

The first issue investigated pertained to the communications network and who should own it. This question asked for a primary response and so would only allow the respondents to pick one answer from the list of choices.

The second question surveyed how the communications network should be used. There are many schools of thought on what should be permitted on certain types of networks, who should be able to utilize that information, how the network should be designed, and more. By providing a list of system characteristics and asking respondents to select all that they felt applied, the researchers were able to assemble a list of preferences for how communications networks, used in support of managed lanes, should operate.

**Incident Management**

Similar to enforcement, incident management activities can involve a different set of partners at both the planning and response levels. The first issue investigated in this section of the survey was the degree of coordination that should be utilized in incident management, at both the planning and response levels.

The second issue presented some common characteristics to incident management operations and questioned respondents as to which of these items would increase the efficiency

of incident management in a managed lanes facility. Each response for this issue took place on a level of 1 through 5. Level 1 represented a rating of "Least Important" and 5 represented a rating of "Most Important." In addition, respondents also had the capability to choose "Not Applicable" (N/A) for each ranking.

### Maintenance

A wide variety of activities falls within the realm of maintenance. The interoperability survey did not attempt to address each individual activity in detail, as this would have significantly increased the length of the survey. The critical input desired from this section was to determine to what extent the range of activities presented in the question would need to be planned for or executed in a manner different than already in use on the mainline facility. The responses to this section of the survey were free-form text answers.

### Conclusions

The conclusion section allowed a respondent to submit free-form text on any other issues they felt important to consider, across all aspects of the interoperability survey.

## CONDUCT OF THE SURVEY

Once the questions were designed and the survey coded into HTML, the survey was placed online at the managed lanes website (http://managed-lanes.tamu.edu), hosted at the Texas Transportation Institute. The survey was placed online in July 2004, and responses were collected through September 10, 2004.

After the survey was tested and put online, the profession was notified via several methods and asked to respond. The first notification took place across the managed lanes Internet listserv, of which there are approximately 300 subscribers. An article was also placed in 'FastLane,' the managed lanes quarterly newsletter. Finally, the notification of the survey was also distributed nationwide by the Transport Communications listserv, which services more than 5000 subscribers.

As respondents answered the survey, the information was automatically entered into the Institute's Oracle database, which served as the data repository. Data recording to the database was actually completed in two phases. The first record entry was performed after the initial page of the survey was completed. Two phases were used to ensure that, in the case of any data or

server problems, the responses to the survey's most important questions on interoperability issues would be recorded. The second data entry procedure was performed at the end of the survey when the rest of the responses were completed. In total, the two data entry procedures logged all survey responses, including numerical and text answers, as well as blank answers.

In order to analyze the data, a program was written to transform the data from the Oracle database structure into a Microsoft® Excel spreadsheet. All calculations, subsequent data manipulation, and analysis were then performed internal to Excel. This transformation program could be run at any time to retrieve the full set of data from all responses received up to that point in time. A simple copy and paste operation of the data into the master analysis spreadsheet was all that was required to update the results with the latest responses. The master spreadsheet was constructed to allow for nearly 500 responses, which would represent a response rate of approximately 9-10 percent from the total number of professionals reached with news of the survey.

## SURVEY ANALYSIS

The majority of the responses to the survey questions were numerical. Recall that on rating questions, a consistent scale was used throughout the survey. The rating scale was:

- 1 – Least Important,
- 2 – Somewhat Important,
- 3 – Important,
- 4 – Very Important,
- 5 – Most Important, and
- N/A – Not Applicable.

On those questions with a numerical rating scale response, the preliminary data analysis technique simply counted the number of responses in each category and divided by the total number of responses to obtain a percentage level for each rating level.

Table 2 illustrates the procedure with the survey response data for the ratings pertaining to Geometric Design from Question 1 of the survey. While this analysis accurately relates the percentages that respondents indicated for each level of interoperability, it is somewhat difficult to determine the consensus response. In other words, while 7 percent of the respondents

indicated a relatively unimportant level of 1 or 2 for coordination of geometric design at the facility level, 18 percent thought it was important, 25 percent very important, and 32 percent most important.

**Table 2. Typical Analysis of Survey Questions.**

| | Responses | | | Percentages | | |
|---|---|---|---|---|---|---|
| | Agency | Facility | Equipment | Agency | Facility | Equipment |
| 1 | 2 | 2 | 8 | 7 | 7 | 29 |
| 2 | 2 | 2 | 8 | 7 | 7 | 29 |
| 3 | 8 | 5 | 4 | 29 | 18 | 14 |
| 4 | 14 | 7 | 1 | 50 | 25 | 4 |
| 5 | 0 | 9 | 4 | 0 | 32 | 14 |
| N/A | 0 | 0 | 1 | 0 | 0 | 4 |
| Non-Blank | 26 | 25 | 26 | 93 | 89 | 93 |
| Blank | 2 | 3 | 2 | 7 | 11 | 7 |
| Total | 28 | 28 | 28 | 100 | 100 | 100 |

In order to more accurately determine a consensus response, the analysis employed a supplementary technique of using a weighted average of the responses to determine a single value for each area and level of interoperability in the question matrix. As an example, consider the following equation to construct a weighted average for the responses received from Geometric Design and Agency level interoperability.

$$\left[(1\times 2)+(2\times 2)+(3\times 8)+(4\times 14)+(5\times 0)\right]\div 26 = 3.308$$

In this equation, the first number in each set of parenthesis represents the value of the rating level, 1 through 5. The second number in each set of parenthesis is the actual number of responses received at that level. Adding them up and diving by the total number of non-blank responses provides a weighted average. This weighted average is a clear consensus response to determine the level of interoperability that respondents answered for each area.

As the final step in the data analysis, researchers computed weighted averages for all areas and levels of interoperability. Table 3 shows the results for Question 1 of the survey. As an example of the power of the weighted average, examination of the results for Geometric Design shows that respondents felt that the facility level interoperability was most important, with a weighted average of 3.76, followed by agency level interoperability with a weighted

average of approximately 3.31. Equipment level interoperability scored significantly less, with a weighted average of approximately 2.31.

**Table 3. Typical Weighted Average Results.**

| | Agency | Facility | Equipment |
|---|---|---|---|
| Geometric Design | 3.133 | 3.897 | 2.483 |
| Operations | 3.700 | 3.862 | 3.645 |
| Enforcement | 3.500 | 3.577 | 3.115 |
| Communications | 3.539 | 3.115 | 3.692 |
| Traffic Control Devices | 3.519 | 4.269 | 3.769 |
| Surveillance & Monitoring | 3.462 | 3.760 | 3.920 |
| Traveler Info Systems | 3.407 | 3.615 | 3.462 |
| Planning | 4.111 | 3.806 | 2.962 |
| Incident Management | 3.556 | 3.962 | 3.231 |
| Maintenance | 2.926 | 3.538 | 3.269 |
| Legislation | 3.778 | 2.769 | 2.462 |
| Evaluation | 3.481 | 3.500 | 2.962 |
| Agency Staffing/Training | 3.481 | 3.000 | 2.731 |

In order to help interpret the results, a scale was applied to the weighted average to categorize the numerical results. Table 4 shows the scale. The determination of the break points in the scale is subjective, based on the researcher's knowledge, survey responses, and literature review. Any weighted response below 3.5 was judged to be not important enough to consider in the task of determining the focus areas for critical interoperability.

**Table 4. Result Scale for Interpreting Weighted Average Computations.**

| Result | Range |
|---|---|
| Somewhat Important | 3.5 - 3.75 |
| Important | 3.75 - 4 |
| Very Important | > 4 |

## SURVEY RESULTS

The results reported below represent a total of 28 responses to the survey on interoperability issues. That represents a response rate of slightly more than 0.5 percent of the

pool of professionals notified about the survey. Although this response rate is slightly lower than typical for an online survey, this survey required some specialized knowledge.

### Major Interoperability Issues

Table 5 shows the weighted averages for each issue and level of interoperability examined in the first section of the survey. Table 5 applies the result scale explained in the previous section and highlights where the critical focus areas of interoperability should be with respect to managed lanes.

**Table 5. Matrix of Interoperability Concerns Developed from Survey.**

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

In Table 5, the most important interoperability issues are represented by the round bullet symbol (●). Issues that were determined to be important are represented by a checkmark symbol (✓). Finally, issues where the weighted average classified the response as somewhat important are represented by the asterisk symbol (✳).

Examination of Table 5 shows that at the agency level, the respondents felt it was most important to address the planning issues for managed lanes. Planning is an expected result that mirrors the literature review, the typical roadway development process, and the general consensus of the researchers.

At the level of facility interoperability, the respondents felt it was most important to address the issue of traffic control devices. This issue has been identified as a critical need in the managed lanes research to date, a finding which is supported by the survey responses.

At the level of equipment interoperability, while none of the items were rated at the highest level of importance, both surveillance and monitoring and traffic control devices were rated as important by the survey respondents. This result is consistent with current practices of how traffic management centers monitor roadways and communicate information to drivers. Interoperability of this equipment is crucial to the efficient and effective management of multiple roadways, even if the operating agency is different.

During the course of the survey, some responses were received for Question 2, where respondents indicated additional issues that they felt were important to be considered in the ranking of major interoperability concerns. Table 6 shows these issues and the ranking they received. The values reported in Table 6 are not weighted averages, as there was only one response for each issue. The values correspond to the ranking scale in use for the survey, where a 1 is "Least Important" and a 5 is "Most Important."

**Table 6. Additional Interoperability Issues and Rankings Identified in Survey.**

| | Agency | Facility | Equipment |
|---|---|---|---|
| HOT lane | 5 | 5 | 5 |
| Emergency response | 5 | 4 | 2 |
| Regional planning and land use input | 4 | 5 | 3 |
| Funding | 5 | 4 | 1 |
| Private Sector financing | 5 | 5 | 5 |
| Local vs. thruway needs | 4 | 5 | 3 |
| Incorporate existing lanes as HOT lanes | 4 | 4 | 4 |
| Environmental and aesthetic impacts | 3 | 5 | 4 |

**Geometric Design**

Researchers evaluated geometric design features in the same manner as interoperability issues. They used a weighted average to determine the consensus response. Table 7 shows the weighted average result for all of the geometric design features utilized in the survey. It can be observed from the results that lane separation and ramp spacing are the two most critical areas of concern, followed closely by ramp design and ramp type. This grouping of features is consistent

with the pressing need to get users of a managed lanes facility on and off in a safe and efficient manner.

Table 8 applies the rating scale to the weighted average results to provide an easy to understand visual interpretation of the results to show the level of importance of each issue. The same markers used previously were also used in Table 8.

**Table 7. Geometric Design Issues – Weighted Average Results.**

| | Weighted Average |
|---|---|
| Ramp Design | 3.842 |
| Ramp Spacing | 4.000 |
| Ramp Type | 3.833 |
| Horizontal Curvature | 2.889 |
| Vertical Curvature | 3.056 |
| Shoulder Widths | 3.471 |
| Lane Width | 3.444 |
| Lane Markings | 3.611 |
| Speed Limits | 2.684 |
| Lane Separation | 4.000 |
| Design of Enforcement Areas | 3.737 |

**Table 8. Geometric Design Issues – Level of Importance.**

| | Level of Importance |
|---|---|
| Ramp Design | ✓ |
| Ramp Spacing | ● |
| Ramp Type | ✓ |
| Horizontal Curvature | |
| Vertical Curvature | |
| Shoulder Widths | |
| Lane Width | |
| Lane Markings | ✳ |
| Speed Limits | |
| Lane Separation | ● |
| Design of Enforcement Areas | ✳ |

The survey also provided the opportunity for respondents to submit and rank additional concerns they felt were missing from the list of geometric design issues. Table 9 shows the responses received in response to this survey question.

**Table 9. Additional Geometric Design Issues and Rankings.**

| | Rating |
|---|---|
| Consistency/Type of lane management strategy | 5 |
| Fly over ramps | 5 |
| Accurate and sufficient advance signage | 5 |
| Physical barrier between HOT lanes & regular | 5 |
| Opportunities for access and egress | 4 |
| Need HOT lane system on majority of congested freeway miles | 5 |

The values reported in Table 9 are not weighted averages, as there was only one response for each issue.

For the final question in the section on geometric design, respondents were asked if they had any additional comments. The following comments were received:

- The goal of the system's lane management strategy should be consistent. If one highway has a management goal of earning revenue and another has the goal of encouraging transit by providing free HOV passage the system goal is inconsistent and ultimately does not provide a true "system."
- Not sure that the design of this survey is going to reveal anything. Everything has to be in place for success and safety.
- I've skipped a few questions that were outside my area of expertise.

## Operations

The weighted averages for operational issues reveal a large number of highly ranked responses. Table 10 shows that respondents feel the majority of operational systems or responses should be coordinated across either the metropolitan area or region. This result highlights the concept of operations as a shared response and responsibility across all the agencies involved with a managed lanes facility.

**Table 10. Weighted Averages for Operational Issues.**

| | Metro | Regional | State | National |
|---|---|---|---|---|
| Traveler Info Systems | 2.789 | 4.368 | 4.150 | 1.789 |
| Incident Response | 4.684 | 2.000 | 2.941 | 4.316 |
| Toll Collection | 4.529 | 2.118 | 4.333 | 3.412 |
| Congestion Management | 4.333 | 4.222 | 2.118 | 2.765 |
| Special Events | 4.389 | 1.471 | 2.059 | 3.944 |
| Homeland Security | 3.833 | 3.412 | 3.778 | 3.529 |
| Emergency Services | 4.556 | 4.389 | 3.059 | 2.353 |
| Enforcement Operations | 4.556 | 4.333 | 2.941 | 1.765 |
| Roadway Monitoring | 4.333 | 4.056 | 1.588 | 2.588 |

In the same manner as other subjects using weighted averages, the result scale was applied to Table 10 to show the level of importance. As seen in Table 11, the results show that respondents felt that relatively few issues needed to be coordinated at either the state or national level.

**Table 11. Operational Issues – Level of Importance.**

| | Metropolitan | Regional | State | National |
|---|---|---|---|---|
| Traveler Info Systems | | ● | ● | |
| Incident Response | ● | | | ● |
| Toll Collection | ● | | ● | |
| Congestion Management | ● | ● | | |
| Special Events | ● | | | ✓ |
| Homeland Security | ✓ | ✳ | ✓ | ✳ |
| Emergency Services | ● | ● | | |
| Enforcement Operations | ● | ● | | |
| Roadway Monitoring | ● | ● | | |

The section on operations provided respondents with the opportunity to identify and rank issues that they felt should have been included in the list presented in the survey. Table 12 shows the results of this question. The values reported in Table 12 are not weighted averages, as there was only one response for each issue.

**Table 12. Additional Operational Issues and Rankings.**

| | Metropolitan | Regional | State | National |
|---|---|---|---|---|
| Private Sector Involvement | 5 | 4 | 2 | 1 |
| Initial Funding | 3 | 4 | 5 | 4 |
| Private Sector Funding | 5 | 5 | 5 | 5 |
| Operations Funding | 5 | 5 | 3 | 3 |

For the final question in the section on operations, respondents were asked if they had any additional comments. The following comment was received:

- Incident Response/Management is one of the keys to potential efficient operation and congestion relief. Effort should be made in Metro/Region to encourage standard protocols, wrecker response, and if possible a single agency for freeway incident/management (i.e., one law enforcement agency).

**Enforcement**

Table 13 showcases the primary results from the section of the survey that dealt with enforcement. The first question in the section focused on who should be creating the enforcement policies. As can be seen from the table, which reports the weighted averages, the highest rankings were determined for Toll Authorities, Emergency Services, and Special Police Forces. This response is somewhat expected given that this method is typically used in Texas to handle enforcement of the managed lanes.

**Table 13. Planning of Enforcement Policies – Rankings.**

| | Rating |
|---|---|
| Local Police | 3.526 |
| Special Police Force | 3.889 |
| State Police | 3.611 |
| Transit Agencies | 3.667 |
| State DOT | 3.647 |
| Toll Authorities | 4.056 |
| Emergency Services | 3.833 |
| Regional Mobility Authority | 2.833 |
| Metropolitan Planning Organization | 2.556 |

In contrast to the planning of enforcement and the high rankings that a number of agencies were accorded, there was little agreement on who should actually do the enforcement. As shown in Table 14, approximately one-third of the respondents felt that either the state police or a special police force should be responsible for application of the enforcement policies. More than half of the survey respondents did not answer this question.

**Table 14. Conduct of Enforcement Activities.**

| Agency | Responses | Percentage |
|---|---|---|
| Local Police | 1 | 3 |
| State Police | 3 | 9 |
| Special Police Force | 6 | 19 |
| Other | 3 | 9 |
| No Answer | 19 | 60 |
| Total | 32 | 100 |

The section on enforcement also investigated what technologies respondents felt would be most useful to the enforcement process. As shown in Table 15, the weighted averages for Electronic Toll Collection and Automatic Vehicle Identification indicate they are both very important technologies to the enforcement process. The ranking of Automated Vehicle Occupancy Detection as an important technology points to a future research need, as no such technology currently exists.

**Table 15. Importance of Enforcement Technologies.**

| Technology | Rating |
|---|---|
| Electronic Toll Collection | 4.556 |
| Automatic Vehicle Identification | 4.056 |
| License Plate Recognition | 3.667 |
| Weight-in-Motion Sensors | 2.611 |
| Speed Detection Tech | 2.722 |
| Auto Vehicle Occupancy Detection | 3.412 |
| Surveillance Cameras | 3.778 |

As a final question related to enforcement, respondents were asked if they had any additional comments. The following comments were received:

- Automated Vehicle Occupancy Detection does not exist

- By charging all vehicles many of the enforcement issues disappear. With growing interest in hybrid cars, HOT lanes could be congested with single-occupancy vehicles (SOVs). Due to occupancy levels the tolls are automatically split by riders and automatically cheaper than SOVs
- Additional facilities and new types of operations will require public education and enforcement. This will require resources to make the facilities successful. "Visible lane permits" is supposed to refer to a sign or decal that motorists in a managed lane display for enforcement purposes, as well as for mainline motorists (to reduce their aggravation about apparent violation rates).
- State legislation needs to be enacted for automated enforcement (via civil/administrative penalty as opposed to criminal penalty) for toll/HOV/managed lane violations much as now allowed for toll violations.

**Communications/Data Exchange**

Many of the activities that take place on managed lanes (such as incident management, enforcement, and traveler information) require information on which to base decisions, actions, and future planning. In fact, designing a communications system for a roadway environment is a complicated process with a number of critical decision points.

One of the primary decision points is the ownership of the telecommunications infrastructure. As shown in Table 16, respondents were fairly ambivalent about the range of options presented in the survey. More than half of the respondents did not answer this question. For those that did, the prominent answer was "Any combination of the above," perhaps representing a 'whatever works' attitude to accomplish the job of getting data from one location to another.

**Table 16. Ownership Options for Communications Infrastructure.**

| | Responses | Percentage |
|---|---|---|
| Leased | 1 | 3 |
| Local Owned | 1 | 3 |
| State Owned | 2 | 6 |
| Any combination of the above | 8 | 25 |
| Other | 2 | 6 |
| Blank | 18 | 57 |
| Total | 32 | 100 |

The two responses received in the 'Other' category were:

- Owned by toll authority, and
- State/Transit/RMA.

This section also investigated what respondents felt should be the main capabilities of the communications network. The results, reported in Table 17, add to more than 100 percent, as respondents were allowed to select multiple characteristics to describe the ideal communications network. A total of 16 of the respondents completed this question of the survey.

**Table 17. Preferred Characteristics for a Communications Infrastructure.**

| | Responses | Percentage |
|---|---|---|
| Use shared communication equipment lines | 12 | 41 |
| Support video and data on the same network | 11 | 38 |
| Send all communications to a central point for dissemination | 11 | 38 |
| Have the ability to send communications to multiple agencies | 15 | 52 |
| Support the needs of: Operations | 14 | 48 |
| Support the needs of: Maintenance | 13 | 45 |
| Support the needs of: Enforcement | 15 | 52 |
| Support the needs of: Traveler Information Systems | 13 | 45 |

As with other sections, the concluding question asked participants if they had any additional comments regarding the topics of communications or data exchange. The participants gave the following comments:

- On private sector HOT lanes they would decide communications system, and
- Not too many opinions on this topic.

**Incident Management**

In freeway management, incident management can be a complex operation involving detailed response scenarios from multiple agencies. The section of the survey first asked respondents if they felt incident management on a managed lanes facility would benefit from the same degree of coordination utilized for the main lanes. Although only 16 respondents answered the question, 100 percent of the responses indicated that incident management would benefit from the same degree of coordination.

Using the coordination question as a base, the next question investigated which agencies should be involved in incident management. There were two components to this question, as survey respondents were asked to look at both the planning and response aspects of incident management. The full results, which are reported in Table 18, will add to more than 100 percent, as respondents were allowed to select multiple answers from the available list. Also note that not all survey respondents provided an answer to the questions in this section of the survey.

**Table 18. Agencies Involved in Incident Management Planning and Response.**

| | Incident Planning | | Incident Response | |
|---|---|---|---|---|
| | Planning | Percentage | Response | Percentage |
| Local Police | 15 | 47 | 12 | 38 |
| Special Police Force | 13 | 41 | 14 | 44 |
| State Police | 13 | 41 | 11 | 34 |
| Transit Agencies | 16 | 50 | 11 | 34 |
| State Department of Transportation | 17 | 53 | 12 | 38 |
| Toll Authorities | 18 | 56 | 9 | 28 |
| Emergency Services | 16 | 50 | 17 | 54 |
| Regional Mobility Authority | 14 | 44 | 3 | 9 |
| Metropolitan Planning Organization | 13 | 41 | 1 | 3 |

The results showcased in Table 18 are fairly consistent in that respondents feel that incident management planning is a shared task involving all the parties listed in the survey. At the planning level, interoperability focuses on creating policies and procedures to create and maintain an effective incident management program.

For the incident response side of the question, there was a slight shift in the answers, as Metropolitan Planning Organization (MPOs) and Regional Mobility Authorities (RMAs) were

seen to not have a significant role in the actual response. This result is consistent with the planning focus of these types of organizations.

The focus for the next question on incident management concentrated on the response itself and what would help that response be successful. As with previous questions, the rating scale of 1 to 5 was used, and a weighted average of all results was constructed. As shown in Table 19, nearly all of the weighted averages are 3.5 or above, indicating that most of these items are considered significant. In fact, there is very little separation in the weighted averages.

**Table 19. Preferred Characteristics for Efficient Incident Management.**

| | Rating |
|---|---|
| Central Dispatching | 3.706 |
| Common Equipment | 3.600 |
| Shared Data Network | 4.000 |
| Shared Radio Frequencies | 3.467 |
| Regional Response Planning | 3.875 |
| Inter-Agency Agreements | 3.688 |

Respondents were also asked if there were any other items that should have been included in the list. Table 20 shows the response and their rankings. Please note that weighted averages are not used since there was only one response for each item listed.

**Table 20. Additional Characteristics for Efficient Incident Management.**

| | Rating |
|---|---|
| Radio Interoperability | 5 |
| Single Command Responsibility | 5 |
| Traffic Management Centers | 4 |
| Media Communication | 4 |
| Alternate Route Planning | 3 |

Respondents were also asked if there were any special incident management strategies that could be used to prevent an incident in the managed lane from affecting the adjacent infrastructure. The following responses were received:

- Visual barriers between HOT lanes and regular lanes ideal.

- Fast response; quick clearance. Respond with just the necessary equipment rather than the full range of emergency responders. Investigate anti-gawk screens. If resources are available, have officers speed traffic up on adjacent facilities.
- Change in law enforcement attitude regarding depth/time of incident investigation. Reduced use of blinking emergency equipment. Quicker removal of incident.

As the final question in this section, respondents were asked if they had any specific comments related to the concept of interoperability and incident management. The following responses were received:

- Provide adequate resources to be the best possible or if privately owned this should happen automatically to improve returns.

**Maintenance**

The final section of the survey examined the interoperability issues of managed lanes and maintenance concerns. Maintenance has typically been considered after a facility has been designed and built, but the access constraints of managed lanes may provide an additional impediment to effective maintenance operations. Respondents were asked to provide any specific comments or concerns related to several maintenance areas. The following responses were received:

- Drainage
  - If managed lanes are barrier separated, areas for water retention and for snow placement are not found within the "typical section." Areas for these functions must be included in the planning and design process.
  - No flooding on the managed lanes.
  - It is very likely that drainage facilities (located on inside shoulder or other) are impacted in the conversion to managed lane operation. Costs to relocate or redesign these facilities can be significant.
  - Very important.
- Road Surface Cleaning
  - Very important.
  - High speed with little room, often inside lane where things build up.

- Repaving
    - Some managed lane facilities are converted shoulders, this leaves no room for maintenance of traffic during resurfacing or incident management.
    - Most important.
    - Should be the "best pavement out there."
- Mowing and Beautification Operations
    - Limited opportunities but similar to divided highways, small (width) areas between moving lanes of traffic should not be greened unless there is a safe clear zone for maintenance activities to occur in.
    - Very important.
- Equipment Upgrades
    - Managed lanes adjacent or within existing highway facilities will require more automation to minimize exposure of personnel.
    - Very important.
- Striping
    - Striped appropriately and once a year.
    - Most important.
    - Must have clear readable markings 24-7.
- Signing and Signal Maintenance
    - Light maintenance systems and other automated devices that reduce personnel exposure to traffic and/or reduce the need for lane closures are important.
    - Most important.
    - Critical to operations.

Respondents were also asked if they had any additional responses on the topic of interoperability and maintenance. The following responses were received:

- All of the above are important, each address a specific requirement and need.
- All the above are normal maintenance activities.
- No comments here.

- While maintenance may likely reduce operations temporarily, design the system so that it will not require shutdown of system.

**Conclusions**

For the final question in the survey, respondents were asked for any additional comments they would like to make regarding interoperability and managed lanes. The following comments were received:

- The 3 toll authorities, major airports, and any new RMAs need to be resolving this issue now. It needs to be very easy for regional and statewide travelers to seamlessly access toll roads, no matter who builds or operates it.
- Reversible lanes should become standard where volumes & ROW justify (two one-way, two one-way & one in opposing direction).
- Get public input in the planning process so you better appreciate public concerns.
- I am interested in the results of your survey. Please share it with the rest of us.

# CHAPTER 4:
# FINDINGS AND RECOMMENDATIONS

## FINDINGS

The successful completion of a managed lanes facility involves a multitude of steps across the planning, design, and operations environments. As a result of the complex interactions that can occur across many aspects of the managed lanes facility, other facilities, and the agencies responsible for their design and operation, interoperability is a key concept to address in the managed lanes concept. Simply put, interoperability is the ability of a system to use the parts, information, or equipment of another system. In this case, the managed lanes facility is one system, and it interacts with other systems or roadways.

One of the key tasks of this research was to determine exactly what forms these interactions take. However, because both interoperability and managed lanes are relatively new concepts in transportation, literature pertaining to these specific subjects is not extensive within the field of transportation. While the specific focus of existing interoperability literature was not within the managed lanes framework, it was obvious that interoperability is a key concept that must be addressed in managed lanes. In many cases, the concepts of interoperability from the other fields in the literature were directly applicable to the managed lanes environment. In fact, a key concept that arose from the literature review is that interoperability exists at multiple levels. For the purposes of a managed lanes environment, these levels were identified as agency, facility, and equipment.

The researchers utilized the results of the literature review to gain general insight into interoperability concepts, areas, and levels. That knowledge was then refined to the specific application of managed lanes through an extensive survey of the profession. While the survey of the profession was comprised of only 24 questions, many questions had multiple parts, many of which utilized a rating scale to determine the level of importance of the topic. As a result, each completed survey generated more than 200 data points. With more than 30 responses to the survey, researchers had a database of more than 6000 individual ratings, text input answers, and respondent comments.

The fact that the results from the literature review (Table 1) closely agree with the results from the survey (Table 5) highlights both the need to address interoperability concerns as

managed lanes move forward, and the consensus view of the profession on what are the critical areas to address.

Table 21 shows the areas where the need for interoperability was rated as either very important or important through the research process. This table is essentially a reorganization of Table 5, focusing on the ranking, instead of the topic area. Similar to the other tables, the results are stratified by the three levels of interoperability, name, agency, facility, and equipment. Each level represents a different aspect of interoperability, and it is critical that each be accomplished using different means. In reality, Table 21 identifies subject areas in the managed lanes manual where interoperability issues should be addressed.

**Table 21. Interoperability Needs in the Managed Lanes Manual.**

| | Agency | Facility | Equipment |
|---|---|---|---|
| Very Important | • Planning | • Traffic Control Devices | |
| Important | • Incident Management | • Geometric Design<br>• Operations<br>• Surveillance and Monitoring<br>• Incident Management | • Surveillance and Monitoring<br>• Traffic Control Devices |

## RECOMMENDATIONS

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

- Planning,
- Geometric Design,
- Traffic Control Devices,
- Operations,
- Incident Management,
- Surveillance and Monitoring, and
- Communications.

In the above listing, although it did not 'make the cut' as an important issue, communications has been added. Communications is a critical component of both surveillance and monitoring and traffic control devices at the equipment level and any discussion of interoperability in the manual would be remiss in neglecting this important facet.

Because the final outline for the managed lanes manual is not complete, a complete list of sections in which interoperability will be addressed is not available. Instead, researchers have created a list of potential sections, by focusing on those issues that received a "Most Important" and "Important" ranking from the survey of the profession.

Sample text for addressing each of these aspects of interoperability has been created and is detailed below. As the manual is completed, modifications to this sample text are expected, and potentially, the areas in which it will be inserted, are expected.

**Sample Text**

*Planning*

Long-term planning is typically the start of any process for building roadway infrastructure. In a managed lanes facility, while planning may be initiated by a particular agency, it is critical that the process reach out to additional agencies who may ultimately be involved in the overall design and daily operations of the facility. However, it is recognized that regional coordination can be a difficult task. In many cases, the definition of what is the region and what agencies should participate in regional discussions are not questions with clear-cut answers. At minimum, all parties involved in the shared infrastructure should be involved in discussions pertaining to the planning aspects. After all, a managed lane is not a stand-alone portion of the roadway infrastructure; it is merely a component of the overall system. In most cases, managed lanes rely on the traditional infrastructure to deliver traffic both to and from the facility.

By addressing system integration or interoperability needs at the onset, agency partners can work together to ensure that a managed lanes facility satisfies the regional mobility goals. In particular, working together, agencies should consider the following minimum aspects of managed lanes planning:

- Establish a regional perspective for transportation and the role of the managed lane.
- Establish a shared customer vision for the managed lanes facility.

- Embrace non-traditional partners at the planning stage, such as emergency service providers.
- Create inter-agency agreements for funding partnerships.
- Create policies for operations and incident management.
- Support the use of geometric guidelines to create safe transitions to and from the facility.
- Establish regional or facility coordination of traffic control devices (signs, signals, and markings), to promote uniformity and to help provide for consistent driver expectations.
- Determine how and by whom the managed lanes facility will be managed.
- Determine what information the managed lanes facility can provide to traveler information systems. At the planning level, this task should focus on the process of what the information needs are, to whom and how often, and not on the specific means of accomplishing information transfers.
- Determine what communications systems are necessary for shared operations.
- Determine what needs exist for effective information exchange with agency partners, third-party information providers, and the traveling public.

*Geometric Design*

Managed lanes are often considered to be a freeway within a freeway and are generally designed to appropriate state or national standards for the class of roadway. However, several aspects of having adjacent freeways are not addressed in those standards. In order to provide the best level of interoperability, adjacent facilities should utilize similar geometric guidelines in order to accommodate the same traffic and not violate any driver expectancy established by the presence of particular geometric standards on the adjacent freeway.

Research has identified ramps as one of the most critical geometric aspects to consider in making a managed lanes facility interoperable with other facilities. In particular, the important aspects to consider in the geometric design of the ramps are ramp type as well as ramp spacing. These guidelines typically vary by traffic level, so understanding both the current and future traffic impact of the facility is important to ensure geometric adequacy both at the time of

construction and in future years of operation. This manual provides significant guidance on these issues.

Other important aspects of geometric interoperability include establishing consistent techniques for lane separation as well as considering the design of specialized areas for enforcement activities.

*Traffic Control Devices*

Traffic control devices are a primary method of sending information to users of any facility. However, due to a lack of established guidelines, managed lanes facilities currently in design or operation have largely had to interpret and improvise to develop traffic control plans. Prior research has noted that these efforts have led to some good practices, but that managed lanes use may be hampered by inconsistencies in use. In addition, motorists may also perceive managed lanes facilities as confusing, limiting their desire to utilize the facility.

To help address these shortcomings, traffic control device interoperability should be considered at two levels. At the facility level, interoperability should focus on the consistency of the information being sent to the motorist. This information includes all types of communication, both verbal and visual, from the use of standard markings, colors, shapes, and terminology, to the specific text utilized to convey payment and enforcement messages. The consistency is achieved by:

- coordinating the above aspects with adjacent infrastructure,
- providing needed information in advance of decision points, and
- in the absence of national or state guidelines, establishing and following regional plans for clear dissemination of information to motorists.

At the equipment level, it should be recognized that many traffic control devices can be utilized to change information, according to the time of day, type of operation in effect, etc. If the facilities are to be used in a shared control capability, this requires, at a minimum, communications and software interfaces that work across multiple types of equipment and that can be accessed and utilized by more than one agency. Additionally, placement and use of traffic control devices should be such that the recipients of the message are clear, e.g., that the messages directed to users of the managed lanes are not interpreted as applying to the adjacent

infrastructure and vice-versa. All of these interoperability issues require foresight and careful planning to accomplish.

*Operations*

The operation of a managed lanes facility is not a simple concept, nor is it a phrase relating to a single concept. Indeed, 'operations' is a complex and multi-faceted plan to achieve safe and efficient movement of goods and people on a facility. A critical component of achieving that goal is considering interoperability, especially at the facility level.

Research identified a number of aspects of operations that were critical to coordinate. Coordination with adjacent or nearby facilities has a number of benefits. First, the agencies involved in the day-to-day operations benefit from having a consistent management plan, especially for items such as incident management and toll collection. Second, the motorists benefit from having consistency between not only a managed lane and the adjacent infrastructure, but also from consistency across all facilities within the region or area. Finally, utilizing shared operations and equipment affords a far quicker mobilization to an area wide emergency, such as a natural disaster or a homeland security event.

Toll collection is certainly one aspect of operations that could provide enormous interoperability benefits, if all facilities utilized a standard method, location, and equipment for paying fares. In particular, research identified the following aspects of operations as gaining benefit from being interoperable across facilities, and potentially, agencies:

- traveler information systems,
- incident management,
- toll collection,
- congestion management,
- special event coordination,
- emergency services,
- enforcement operations, and
- roadway monitoring.

These and other aspects of operations can be coordinated through the creation of shared policies and procedures, pre-established action plans, with priority of implementation, and the

use of shared management and potentially, control of equipment, especially in response type activities.

*Incident Management*

Incident management is an activity typically associated with the operations of a managed lanes facility. While incident management is a critical component in which to ensure interoperability, the reader is referred to the section on operations for discussions of this activity.

*Surveillance and Monitoring*

One of the most basic activities used to help achieve smooth flowing operations on any facility is to monitor the roadway for any changes or conditions that may indicate the presence of congestion or incidents. Early detection of these conditions combined with a prompt response can decrease the timeframe of disruption and restore the facility to smooth operations.

This surveillance can be done through the use of sensors, which relay data about the roadway characteristics, such as speed and occupancy. Surveillance can also be performed through the use of video, in which operators or automated readers examine the pictures for any changes that would indicate the presence of breakdown conditions.

At the facility level, one aspect of achieving interoperability might focus on the use of shared management centers, although this not a requirement for successful operations. Today, the concept of multiple agencies sharing a traffic management center is commonplace and helps to increase the coordination of the agencies and the efficiency of the facilities.

Another aspect to achieving facility level interoperability in surveillance and monitoring capabilities is participation in traveler information systems, to help ensure a comprehensive view of transportation mobility.

At the equipment level, achieving interoperability with surveillance and monitoring has a myriad of aspects, including:

- the support for multiple communications systems to exchange data,
- the use of common communications protocols to support data exchange,
- the use of common messages sets and data elements to construct information, and
- particular to video surveillance, the support for multicast communications to enable video reception at multiple agencies or endpoints.

Note that the above is not a recommendation for establishing a single vendor solution for surveillance and monitoring equipment. While uniformity has many appealing aspects, such as cost reductions and decreased support problems, uniformity is not a prerequisite to successful interoperability.

*Communications*

Interoperability with respect to communications can be achieved in multiple ways. Communications is one area where the expression "one size fits all" most certainly does *not* apply. Even if different equipment and vendors are used, the use and support of common protocols, message sets, and data elements can enable the smooth transfer of data between multiple agencies. Be careful of systems requiring proprietary protocols, as they are not the wave of the future.

If there are multiple agencies involved, the key concepts to understand are the design of the overall communications network in which the managed lane will participate. Some of the critical items to be aware of are:

- What communications systems will be used to exchange data?
- What protocols will be used for data exchange?
- What message sets and data elements will be used to send and receive information?
- What data formats will be supported?
- What video formats will be supported?
- What video distribution mechanisms will be supported?

It should be noted that understanding the above requirements allows for the use of multiple vendors within the communications systems. While uniformity has many appealing aspects, it is not a prerequisite to successful interoperability.

**Future Research Needs**

The research team identified a number of questions or open issues during the course of this research. The existing literature does not contain adequate references to provide guidance on these topics. While the list below is not exclusively related to interoperability, it is presented

for the sake of completeness, as many topics were identified by the survey respondents. The complete list of topics where research is still needed is:

- managed lanes and their participation in 511 Interoperability,
- shifting the transit ridership model,
- coordination of public/private funding across agencies for managed lanes,
- environmental impacts of managed lanes,
- aesthetic concerns of managed lanes,
- consistency in the application of lane management strategies,
- performance measures to support managed lanes operations,
- types and application of barrier separation between main lanes and managed lanes, and
- legislative support for automated enforcement.

# REFERENCES


1. Merriam Webster Online. Definition of Interoperability. http://www.m-w.com/cgi-bin/dictionary?book=Dictionary&va=interoperability. Accessed August 15, 2004.
2. Texas Transportation Institute (TTI). *Fastlane.* College Station, Texas: TTI, Spring 2004.
3. Collier, Tina, and Ginger Daniels Goodin. *The Funding and Financing of Managed Lanes.* Project 0-4160/Bulletin 4160-9B. College Station, Texas: Texas Transportation Institute (TTI), 2002.
4. Karr, Al. *Building the Bridge Between ITS.* TM+E Magazine, April/May 2002.
5. Miller, Mark A., and Amy Lam. *Institutional Aspects of Multi-Agency Transit Operations.* California PATH Research Report UCB-ITS-PRR-2003-18. Berkeley, California: California Partners for Advanced Transit and Highways, April 2003.
6. National Task Force on Interoperability (NTFI). *Why Can't We Talk?: Working Together to Bridge the Communications Gap to Save Lives*. NTFI, February 2003.
7. Federal Highway Administration (FHWA), Federal Transit Administration (FTA), Volpe National Transportation System Center. *Linking Regional Planning and Operations for Effective ITS Deployment Proceedings*. Washington D.C.: FHWA, December 1996.
8. Corbin, John, and Patricia B. Noyes. *Traffic Incident Management Planning: The Case for Mainstreaming.* ITE Journal. February 2003.
9. Hochmuth, Jeff, and Syd Bowcott. *The GCM Corridor Gateway – Overcoming the Issues.* November 1999.
10. Christie, Blake, and Susan Proper. *ITS Standards Implementation – Interoperability Issues and Solutions,* ITS America 12th Annual Meeting, Long Beach, California, May 2002.

# APPENDIX:
# SURVEY OF THE PROFESSION

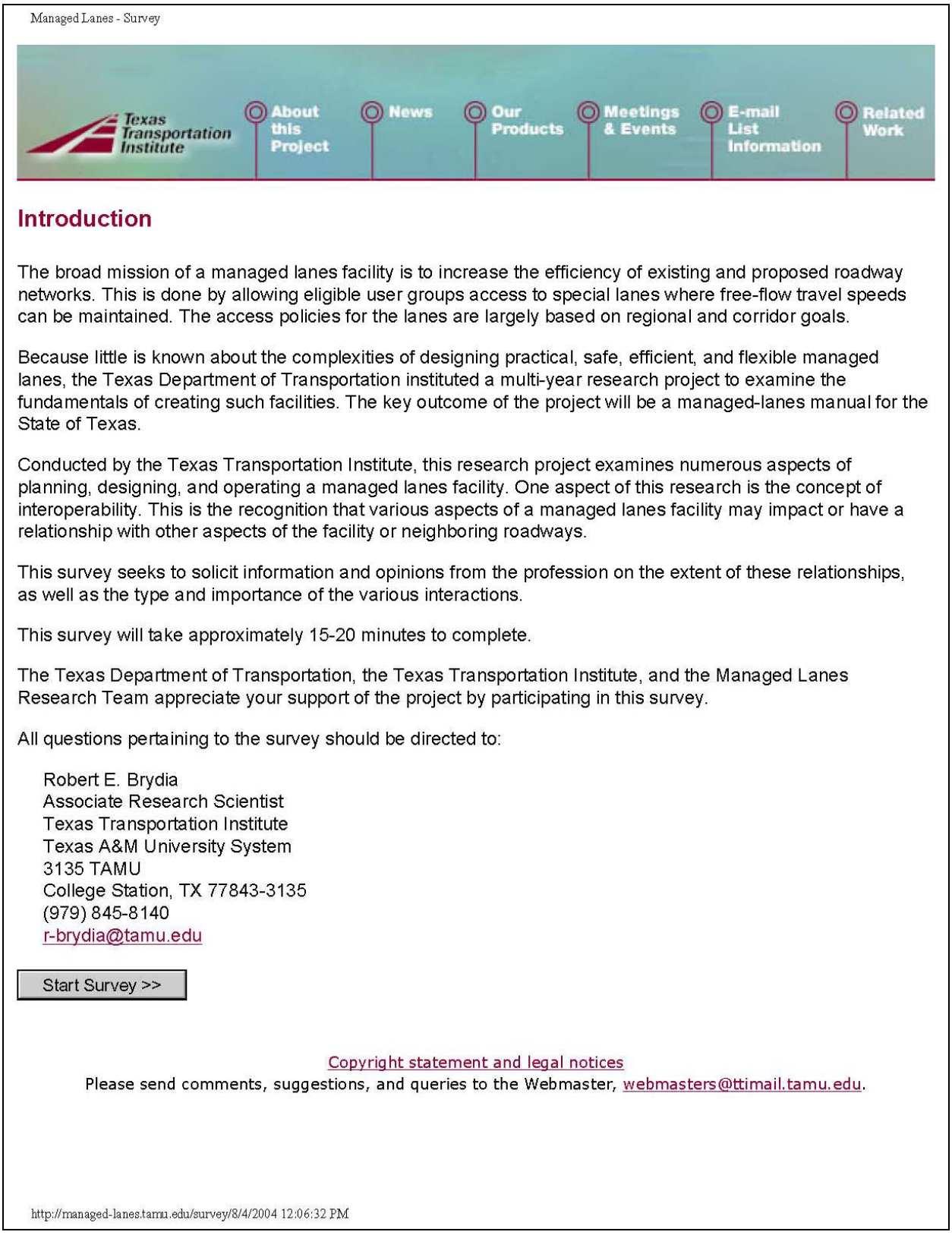
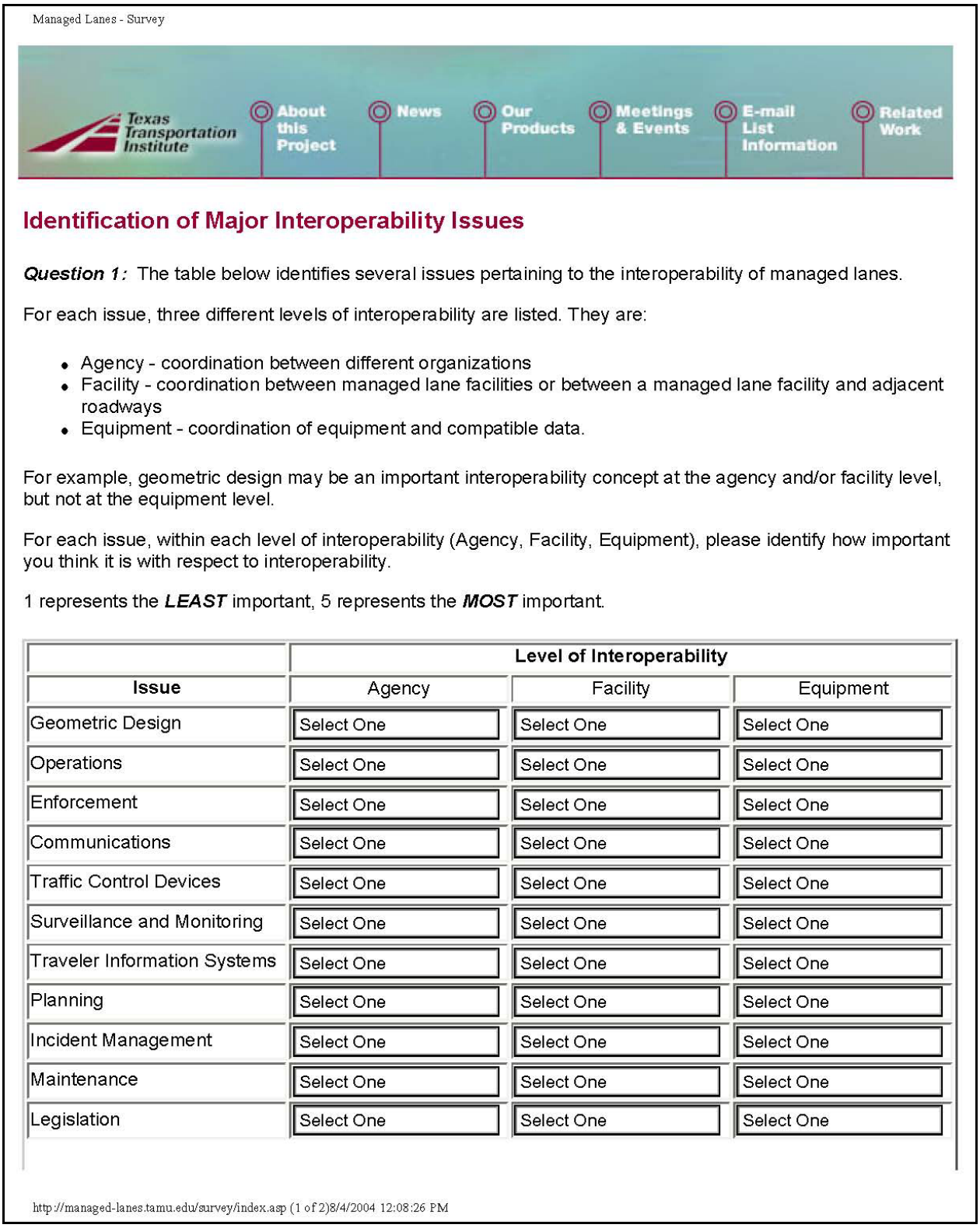



**Figure A1. Survey Introduction.**



Managed Lanes - Survey

Texas Transportation Institute | About this Project | News | Our Products | Meetings & Events | E-mail List Information | Related Work

## Identification of Major Interoperability Issues

***Question 1:*** The table below identifies several issues pertaining to the interoperability of managed lanes.

For each issue, three different levels of interoperability are listed. They are:

- Agency - coordination between different organizations
- Facility - coordination between managed lane facilities or between a managed lane facility and adjacent roadways
- Equipment - coordination of equipment and compatible data.

For example, geometric design may be an important interoperability concept at the agency and/or facility level, but not at the equipment level.

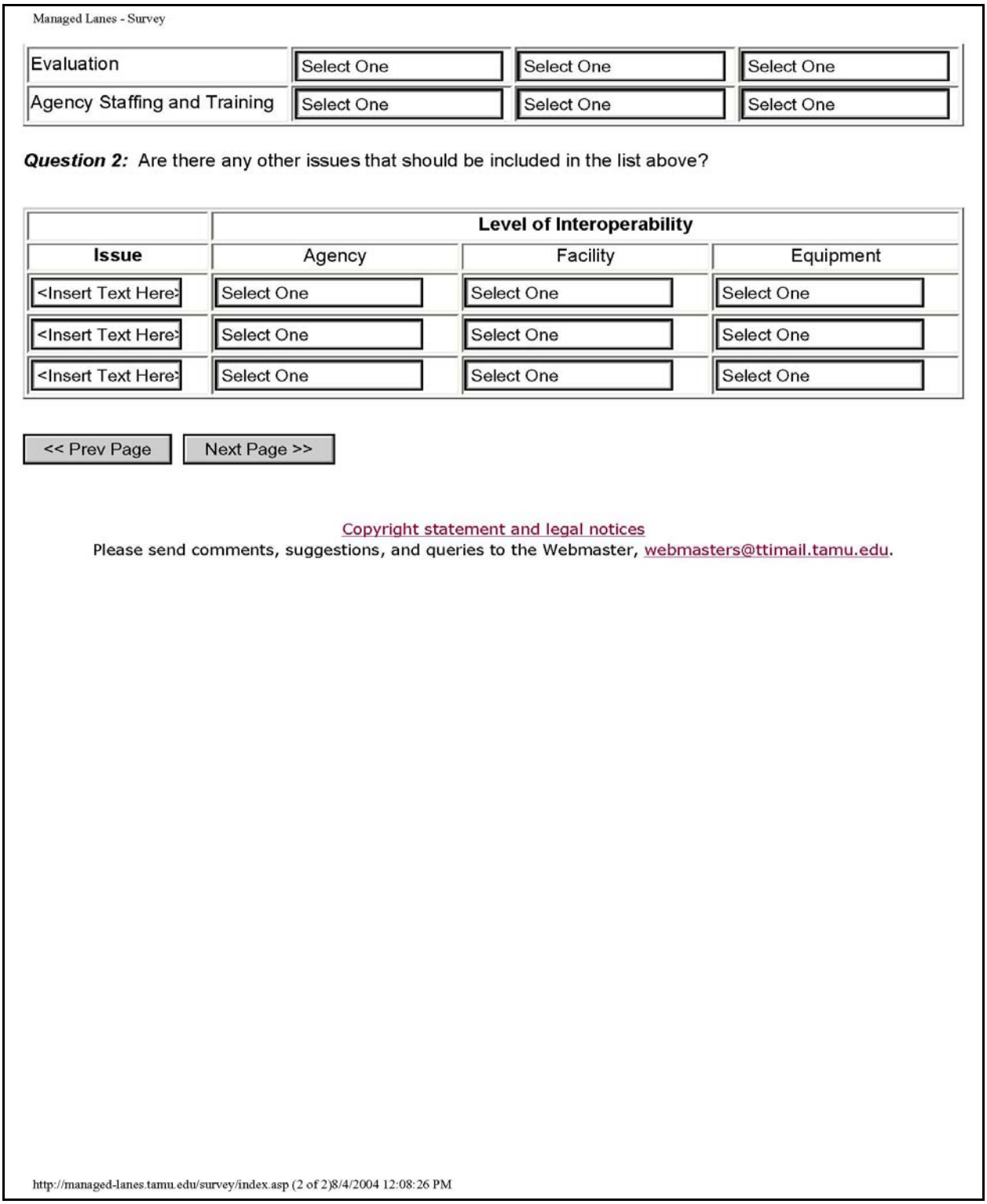
For each issue, within each level of interoperability (Agency, Facility, Equipment), please identify how important you think it is with respect to interoperability.

1 represents the ***LEAST*** important, 5 represents the ***MOST*** important.

| | Level of Interoperability | | |
|---|---|---|---|
| **Issue** | Agency | Facility | Equipment |
| Geometric Design | Select One | Select One | Select One |
| Operations | Select One | Select One | Select One |
| Enforcement | Select One | Select One | Select One |
| Communications | Select One | Select One | Select One |
| Traffic Control Devices | Select One | Select One | Select One |
| Surveillance and Monitoring | Select One | Select One | Select One |
| Traveler Information Systems | Select One | Select One | Select One |
| Planning | Select One | Select One | Select One |
| Incident Management | Select One | Select One | Select One |
| Maintenance | Select One | Select One | Select One |
| Legislation | Select One | Select One | Select One |

http://managed-lanes.tamu.edu/survey/index.asp (1 of 2)8/4/2004 12:08:26 PM

**Figure A2. Questions Pertaining to the Identification of Major Interoperability Issues.**



Managed Lanes - Survey

| | | | |
|---|---|---|---|
| Evaluation | Select One | Select One | Select One |
| Agency Staffing and Training | Select One | Select One | Select One |

***Question 2:*** Are there any other issues that should be included in the list above?

| | Level of Interoperability | | |
|---|---|---|---|
| **Issue** | Agency | Facility | Equipment |
| <Insert Text Here> | Select One | Select One | Select One |
| <Insert Text Here> | Select One | Select One | Select One |
| <Insert Text Here> | Select One | Select One | Select One |

<< Prev Page  Next Page >>

Copyright statement and legal notices

Please send comments, suggestions, and queries to the Webmaster, webmasters@ttimail.tamu.edu.

http://managed-lanes.tamu.edu/survey/index.asp (2 of 2)8/4/2004 12:08:26 PM

**Figure A2. Questions Pertaining to the Identification of Major Interoperability Issues. (Cont.)**

Managed Lanes - Survey


## Geometric Design

Within the area of geometric design, standard practice and research-to-date have identified numerous issues as being important to the design of managed lanes.

***Question 3:*** For each geometric design issue listed below, please consider the importance of the issue in terms of ensuring the compatibility of managed lanes with adjacent infrastructure.

1 represents the ***LEAST*** important, 5 represents the ***MOST*** important.

| Issue | Rating |
|---|---|
| Ramp Design | Select One |
| Ramp Spacing | Select One |
| Ramp Type (direct-connect vs. mainlane slip) | Select One |
| Horizontal Curvature | Select One |
| Vertical Curvature | Select One |
| Shoulder Widths | Select One |
| Lane Width | Select One |
| Lane Markings | Select One |
| Speed Limits | Select One |
| Lane Separation (barrier / buffer / free-entry) | Select One |
| Design of Enforcement Areas | Select One |

***Question 4:*** Are there any other issues that you feel should be included in the list above?

| Issue | Rating |
|---|---|
| <Insert Text Here> | Select One |
| <Insert Text Here> | Select One |
| <Insert Text Here> | Select One |



**Figure A3. Questions Pertaining to Geometric Design.**

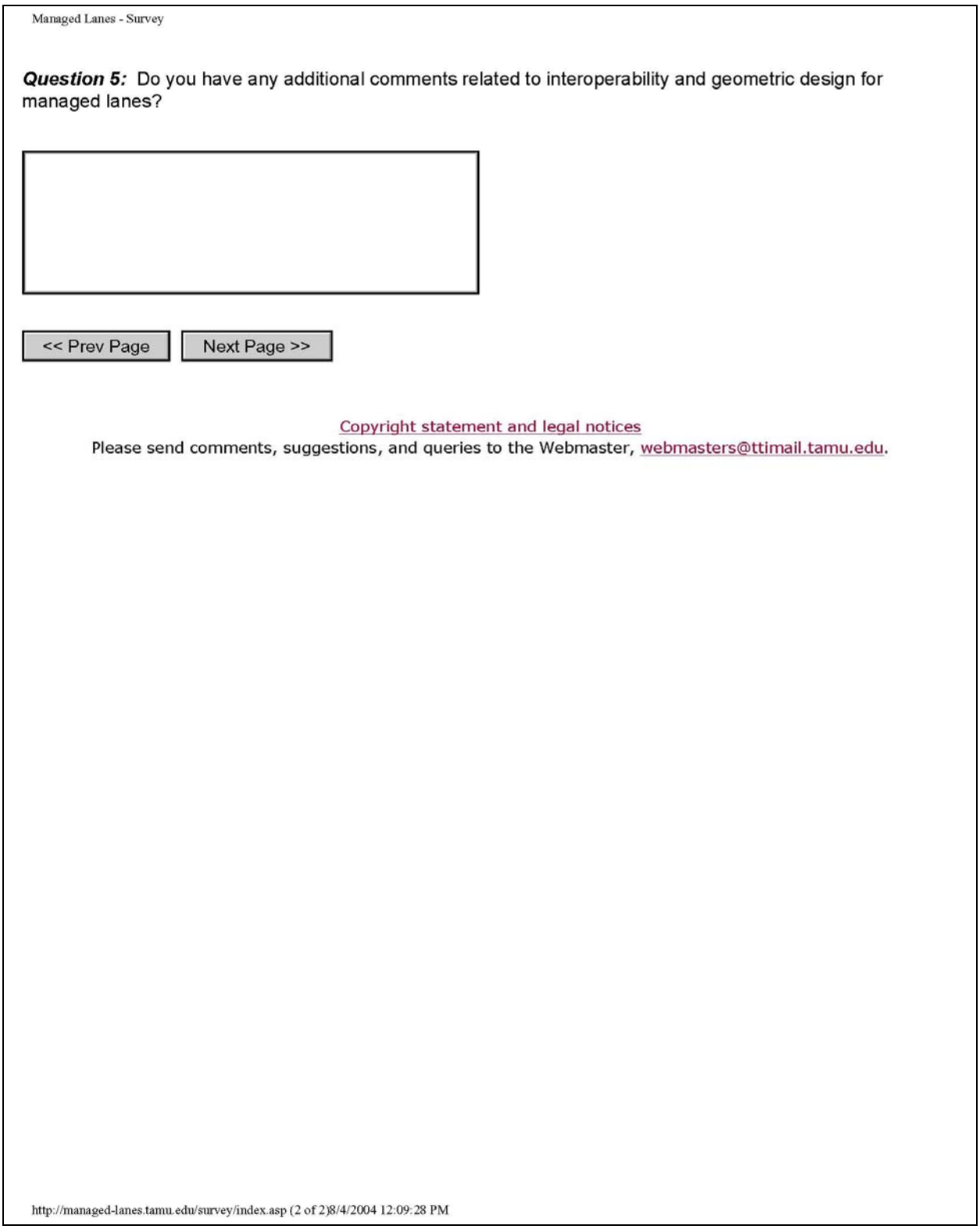



**Figure A3. Questions Pertaining to Geometric Design. (Cont).**


## Operations

Interoperability in operations can take many forms. From incident management responses to unified toll collection activities, the efficiency of the managed lanes can be enhanced by coordinating their operations with other facilities.

This question addresses what activities are the most important to coordinate, and at which level that coordination should take place.

***Question 6:*** For each operational issue listed below, four levels of coordination are listed. They are:

- Metropolitan - coordination across the city
- Regional - coordination across the city and surrounding areas
- State - coordination across the entire state
- National - coordination across the United States

For each issue, within each level, please identify how important you think it is.

1 represents the ***LEAST*** important, 5 represents the ***MOST*** important.

| | Level of Coordination | | | |
|---|---|---|---|---|
| **Issue** | Metro | Regional | State | National |
| Traveler Information Systems | Select One | Select One | Select One | Select One |
| Incident Response | Select One | Select One | Select One | Select One |
| Toll Collection | Select One | Select One | Select One | Select One |
| Congestion Management | Select One | Select One | Select One | Select One |
| Special Events | Select One | Select One | Select One | Select One |
| Homeland Security | Select One | Select One | Select One | Select One |
| Emergency Services | Select One | Select One | Select One | Select One |
| Enforcement Operations | Select One | Select One | Select One | Select One |
| Roadway Monitoring | Select One | Select One | Select One | Select One |

***Question 7:*** Are there any other issues that you feel should be included in the list above?



**Figure A4. Questions Pertaining to Operations.**

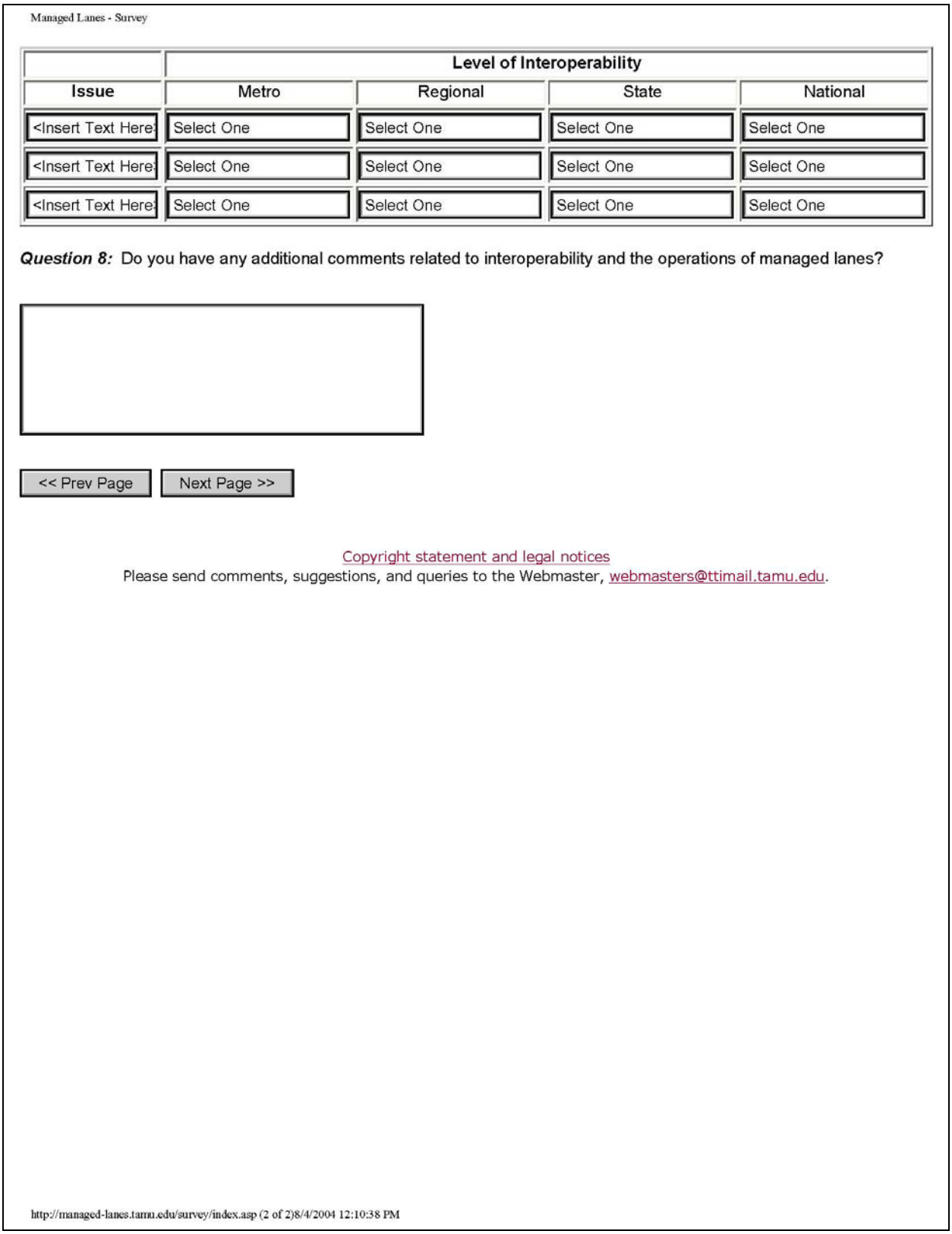



**Figure A4. Questions Pertaining to Operations. (Cont).**


## Enforcement

A successful managed lane requires effective enforcement to maintain the level of service appropriate to the management strategy in place.

While it is the responsibility of enforcement agencies to maintain the integrity of the facility, any number of organizations can cooperate to create the enforcement policies and procedures.

***Question 9:*** Please rate the importance of each agency's involvement in creating these enforcement policies.

1 represents the ***LEAST*** important, 5 represents the ***MOST*** important.

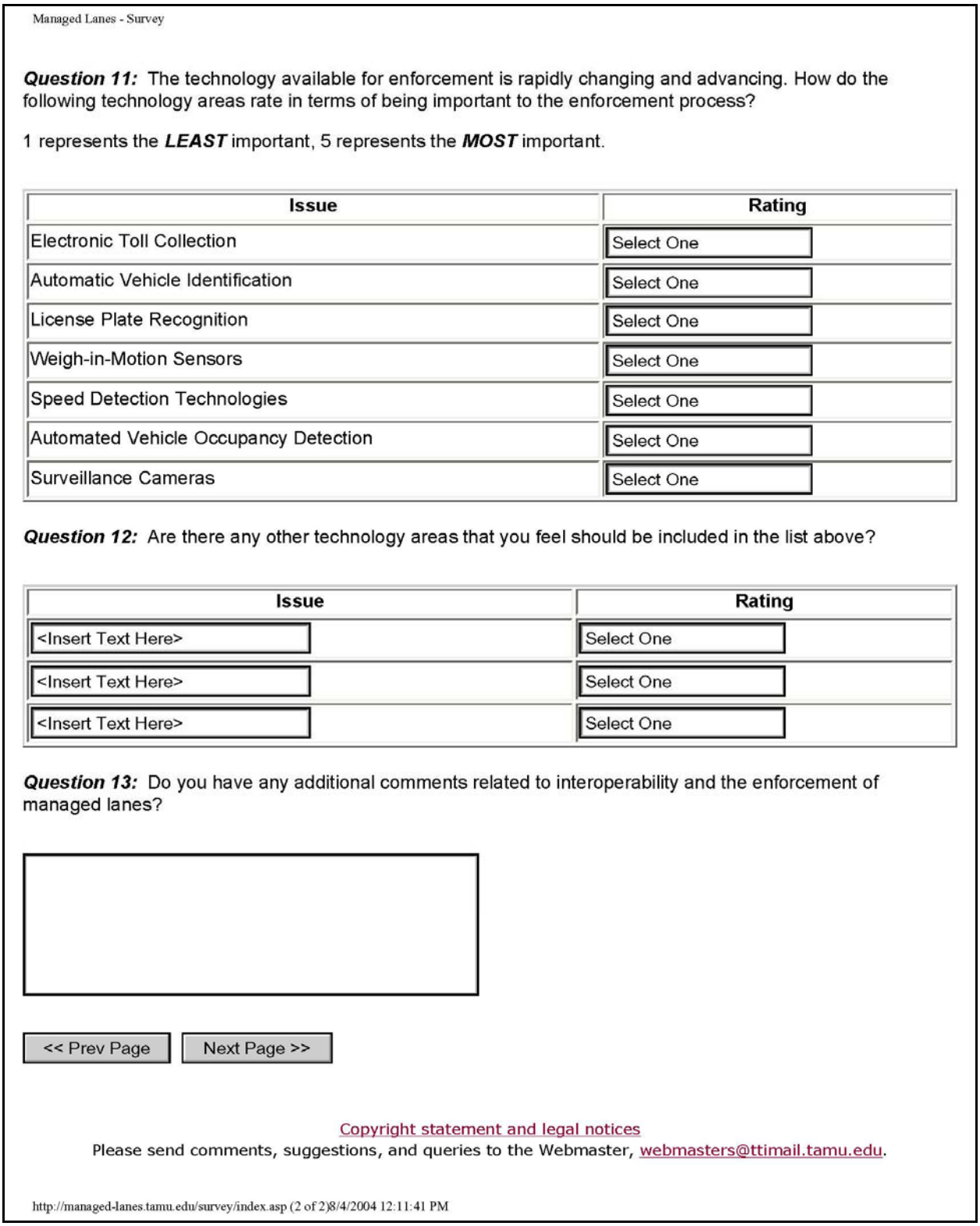
| Agency | Rating |
|---|---|
| Local Police | Select One |
| Special Police Force (ex: transit agency law enforcement) | Select One |
| State Police | Select One |
| Transit Agencies | Select One |
| State Department of Transportation | Select One |
| Toll Authorities | Select One |
| Emergency Services | Select One |
| Regional Mobility Authority | Select One |
| Metropolitan Planning Organization | Select One |

***Question 10:*** Who should primarily be responsible for the enforcement of managed lanes? (Please select only one)

| Agency | |
|---|---|
| Local Police | O |
| State Police | O |
| Special Police Force (ex: transit agency law enforcement) | O |
| Other <Insert Text Here> | O |



**Figure A5. Questions Pertaining to Enforcement.**



Managed Lanes - Survey

***Question 11:*** The technology available for enforcement is rapidly changing and advancing. How do the following technology areas rate in terms of being important to the enforcement process?

1 represents the ***LEAST*** important, 5 represents the ***MOST*** important.

| Issue | Rating |
|---|---|
| Electronic Toll Collection | Select One |
| Automatic Vehicle Identification | Select One |
| License Plate Recognition | Select One |
| Weigh-in-Motion Sensors | Select One |
| Speed Detection Technologies | Select One |
| Automated Vehicle Occupancy Detection | Select One |
| Surveillance Cameras | Select One |

***Question 12:*** Are there any other technology areas that you feel should be included in the list above?

| Issue | Rating |
|---|---|
| <Insert Text Here> | Select One |
| <Insert Text Here> | Select One |
| <Insert Text Here> | Select One |

***Question 13:*** Do you have any additional comments related to interoperability and the enforcement of managed lanes?

<< Prev Page | Next Page >>

Copyright statement and legal notices

Please send comments, suggestions, and queries to the Webmaster, webmasters@ttimail.tamu.edu.

http://managed-lanes.tamu.edu/survey/index.asp (2 of 2)8/4/2004 12:11:41 PM

**Figure A5. Questions Pertaining to Enforcement. (Cont).**


## Communications / Data Exchange

The information necessary to support the daily operations and management of a managed lane facility can be significant. This information may be exchanged with partner agencies, equipment, enforcement, vehicles, and the traveling public. A large scale and robust communications data network may be required to support these needs.

***Question 14:*** Should communication networks for managed lane facilities primarily be: (Please select only one)

| | |
|---|---|
| Leased from utility or telecommunication companies | O |
| Owned and shared by local agencies | O |
| Owned by the states | O |
| Any combination of the above | O |
| Other <Insert Text Here> | O |

***Question 15:*** Should a managed lane communications network: (Check all that apply)

| | |
|---|---|
| use shared communication equipment lines (multiple devices per line) | ☐ |
| support video and data on the same network | ☐ |
| send all communications to a central point for dissemination | ☐ |
| have the ability to send communications to multiple agencies / partners | ☐ |
| Support the needs of:<br>Operations | ☐ |
| Maintenance | ☐ |
| Enforcement | ☐ |
| Traveler Information Systems | ☐ |

***Question 16:*** Do you have any additional comments related to the interoperability of communication systems for managed lanes?



**Figure A6. Questions Pertaining to Communications / Data Exchange.**

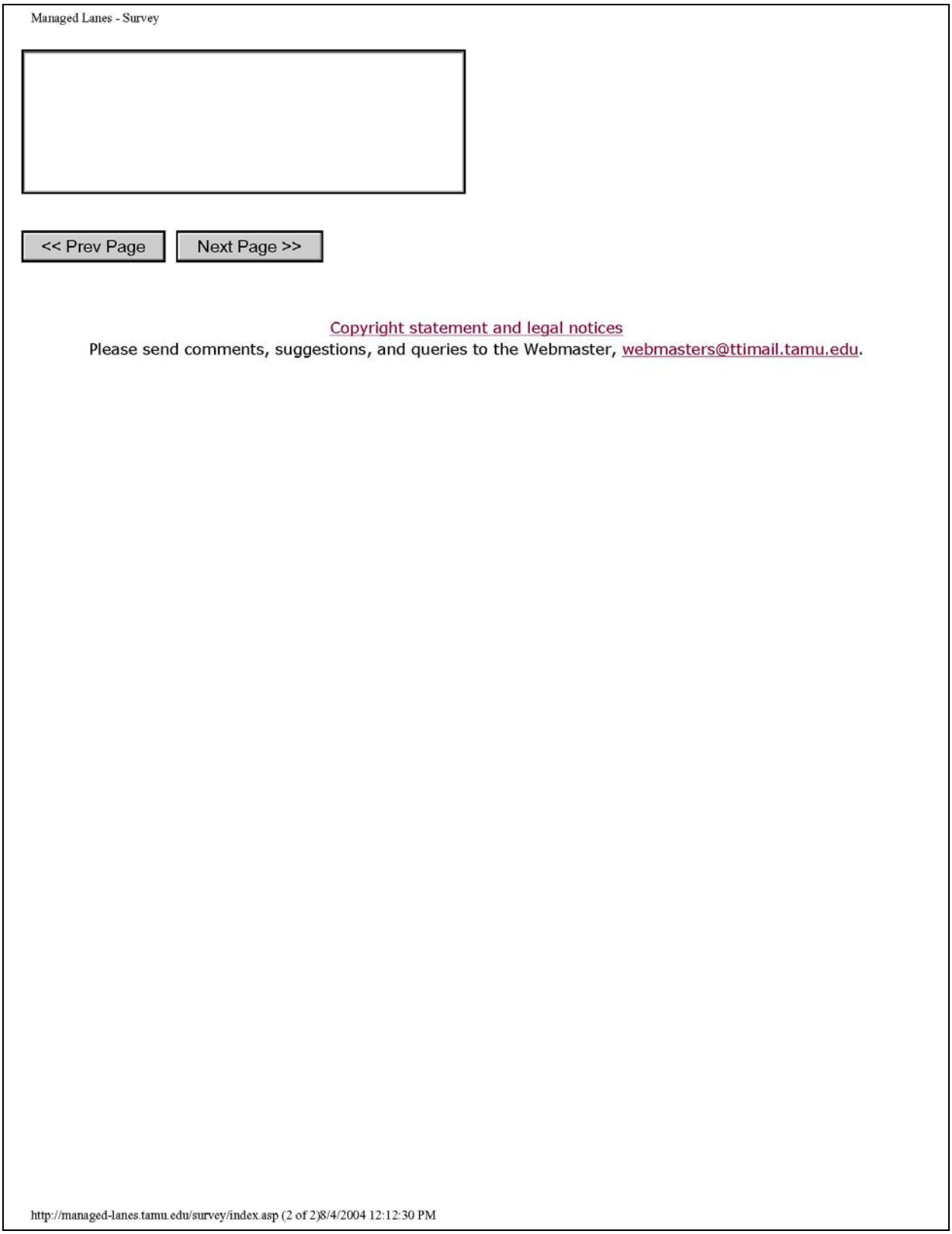



**Figure A6. Questions Pertaining to Communications / Data Exchange. (Cont).**


## Incident Management

The state-of-the-practice has shown that incident management can benefit greatly from increased coordination between agencies. In fact, most traffic management centers or roadway coalitions have active programs to share items such as information, equipment, or personnel to respond as quickly and efficiently as possible to roadway incidents.

***Question 17:*** Will the same degree of coordination be beneficial to incident management on a managed lane facility? (Please select only one)

- O Yes
- O No
- O Not Sure

***Question 18:*** What agencies should be involved in incident management activities on a managed lane facility? (Check all that apply)

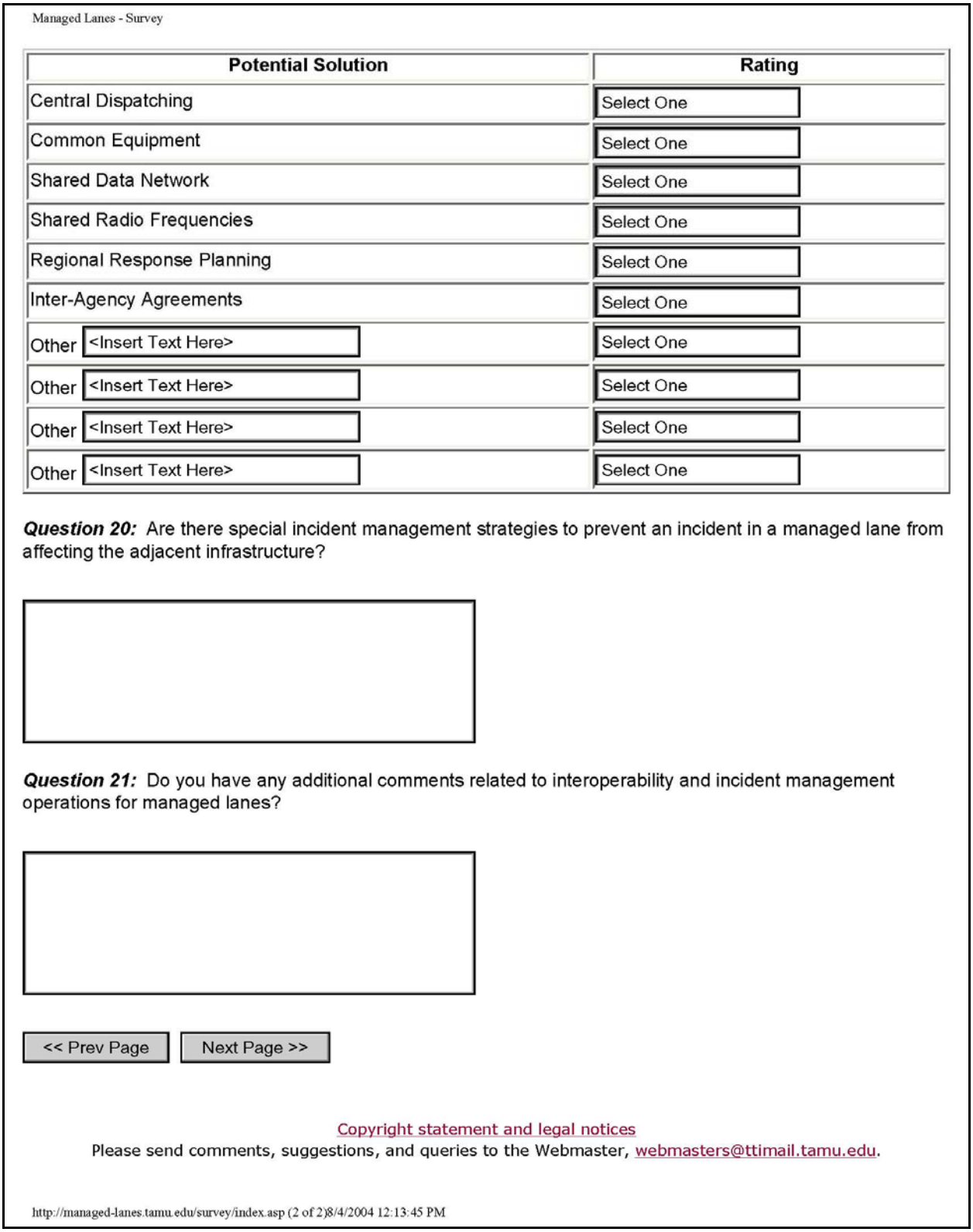
| Agency | Planning | Response |
|---|---|---|
| Local Police | ☐ | ☐ |
| Special Police Force (ex: transit agency law enforcement) | ☐ | ☐ |
| State Police | ☐ | ☐ |
| Transit Agencies | ☐ | ☐ |
| State Department of Transportation | ☐ | ☐ |
| Toll Authorities | ☐ | ☐ |
| Emergency Services | ☐ | ☐ |
| Regional Mobility Authority | ☐ | ☐ |
| Metropolitan Planning Organization | ☐ | ☐ |

***Question 19:*** How important would the following potential solutions be to support more efficient incident management in a managed lane facility?

1 represents the ***LEAST*** important, 5 represents the ***MOST*** important.



**Figure A7. Questions Pertaining to Incident Management.**


Managed Lanes - Survey

| Potential Solution | Rating |
|---|---|
| Central Dispatching | Select One |
| Common Equipment | Select One |
| Shared Data Network | Select One |
| Shared Radio Frequencies | Select One |
| Regional Response Planning | Select One |
| Inter-Agency Agreements | Select One |
| Other <Insert Text Here> | Select One |
| Other <Insert Text Here> | Select One |
| Other <Insert Text Here> | Select One |
| Other <Insert Text Here> | Select One |

***Question 20:*** Are there special incident management strategies to prevent an incident in a managed lane from affecting the adjacent infrastructure?

***Question 21:*** Do you have any additional comments related to interoperability and incident management operations for managed lanes?

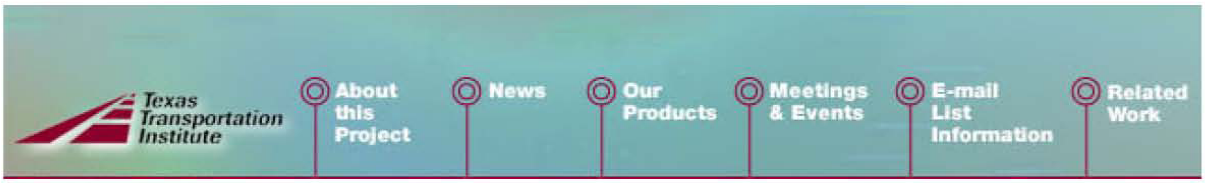
<< Prev Page | Next Page >>

Copyright statement and legal notices

Please send comments, suggestions, and queries to the Webmaster, webmasters@ttimail.tamu.edu.

http://managed-lanes.tamu.edu/survey/index.asp (2 of 2)8/4/2004 12:13:45 PM

**Figure A7. Questions Pertaining to Incident Management. (Cont).**




## Maintenance

***Question 22:*** Maintenance operations have generally been considered after a facility is planned and designed. Are there specific concerns related to any of the following maintenance practices that should be considered early in the planning and design process of the facility?

| Maintenance Issue | Concern |
|---|---|
| Drainage | |
| Road Surface Cleaning | |
| Repaving | |
| Mowing and Beautification Operations | |
| Equipment Upgrades | |
| Striping | |
| Signing and Signal Maintenance | |
| Other <Insert Text Here> | |
| Other <Insert Text Here> | |
| Other <Insert Text Here> | |

***Question 23:*** Do you have any additional comments related to interoperability and maintenance operations in a managed lane facility?



**Figure A8. Questions Pertaining to Maintenance.**

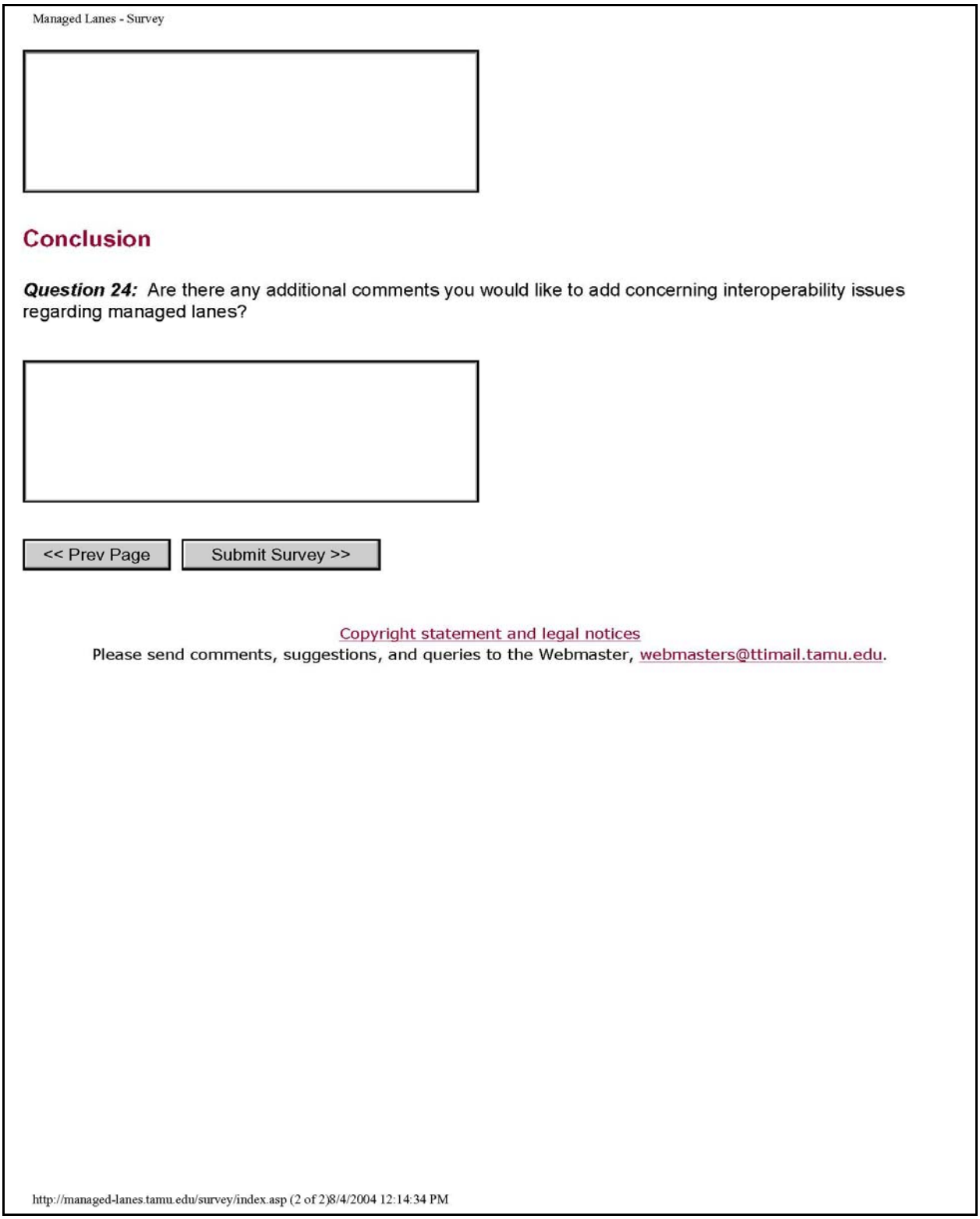



**Figure A8. Questions Pertaining to Maintenance. (Cont).**