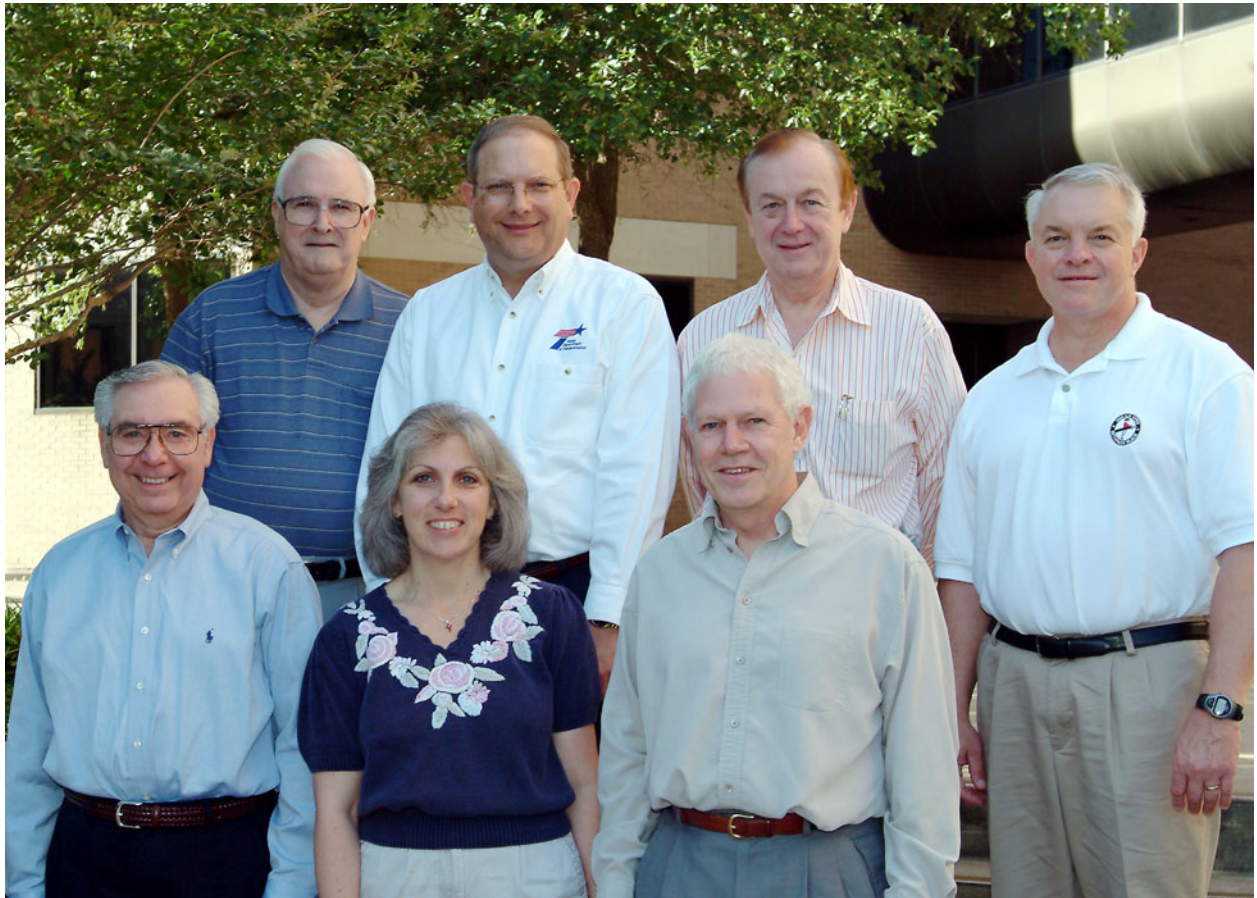


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COMPENDIUM:
PAPERS ON
ADVANCED SURFACE TRANSPORTATION SYSTEMS
AUGUST 2003



Class Instructor and Mentors (front row, from left) Conrad Dudek, Marsha Anderson Bomar, James Wright, (back row) Wayne Shackelford, Gary K. Trietsch, Walter Kraft, Thomas Werner

PREFACE

This document is the culmination of the thirteenth offering of a Mentors Program at Texas A&M University on Advanced Surface Transportation Systems that was presented in 2003 by the Advanced Institute in Transportation Systems Operations and Management. The Program allows participants to work closely with recognized experts in the fields of intelligent transportation systems (ITS) and traffic operations and management. The highly successful Mentors Program has been available to transportation engineering graduate students at Texas A&M University since 1991.

As part of the Mentors Program six top-level transportation professionals from private enterprise and departments of transportation, were invited to Texas A&M University to present a 1½-day Symposium on Advanced Surface Transportation Systems in early June. Immediately following the Symposium, the participants enrolled in the Program took part in a Forum and a Workshop with the invited mentors and the course instructor. Each participant held numerous discussions with the mentors and the course instructor to identify a topic area for a paper. The state DOT participants selected topics that had direct application to the needs of their respective states. Each participant worked with his/her mentor and course instructor to finalize a topic area and objectives for a paper. In addition to discussions with the course instructor, the participants (communicating via telephone, e-mail, fax, and mail) worked directly with the mentors throughout the summer while preparing their papers. The mentors and the state DOT employee participants returned to the Texas A&M University campus in early August for formal presentations of the papers.

One important objective of the Program was to develop rapport between the participants and the mentors. The opportunity for the participants to communicate and interact with the mentors, who are recognized for their knowledge and significant contributions both nationally and internationally, was a key element for the participants to gain the type of learning experiences intended by the instructor. Therefore, extra care was taken to encourage interaction through the Symposium, Forum, Workshop, and social events.

Marsha Anderson Bomar, Walter Kraft, Wayne Shackelford, Gary K. Trietsch, Thomas Werner, and James Wright devoted considerable time and energy to this Program. We are extremely grateful for their valuable contributions in making the 2003 Mentors Program such a huge success.

The opportunity to bring top-level transportation professionals to the campus was made possible through financial support provided by the University Transportation Centers Program of the U.S. Department of Transportation to the Southwest Region University Transportation Center at TTI.

Joan Stapp, Senior Secretary with the Texas Transportation Institute, coordinated the Symposium and Workshop in a very efficient and professional manner.



Congratulations are extended to the participants who completed the Program. Their papers are presented in this Compendium. The transportation professionals who graciously served as mentors in previous years and the participants in the Advanced Institute Program since 1991 are shown in Appendices A, B, and C. A listing of all the papers prepared by the participants since 1991 is shown in Appendix D.

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2003 MENTORS**MARSHA ANDERSON BOMAR**

In 1990, Marsha Anderson Bomar formed *Street Smarts*, a transportation planning and engineering consulting firm based in Atlanta, Georgia. She had the honor of being the first woman to serve as International President of the Institute of Transportation Engineers. Ms. Bomar has received the Gwinnett County Chamber of Commerce Athena Award. This is given to the Outstanding Businesswoman who has made a significant contribution in business, community service and her profession. In 2003, Marsha was the recipient of the Institute of Transportation Engineers Burton Marsh Award, given to a person who has made outstanding contributions to the advancement of ITE throughout a period of several years.



Ms. Bomar has been responsible for a wide range of technical projects. In the past several years, she has led the effort on the application of handheld computer technology for data collection applications, as well as designing a transit system to serve the cultural and historic sights of Atlanta using Electric Vehicle technology, and assisted in the planning for the Advantage I-75 corridor and the I-95 Corridor Coalition. Currently, she is the Project Manager for a major study for the DOT investigating and implementing strategies for managing Truck Traffic in the Atlanta metro area.

Ms. Bomar is past Chair of the Institute of Transportation Engineers' Technical Council Design Department, Policy Committee, Transportation Planners Council and Goods Movement Council. She was a Director of the New Jersey Motor Truck Association, as well as the American Trucking Associations' Scholar-In-Residence. Other affiliations include the numerous Transportation Research Board committees, NCHRP Panels, Women's Transportation Seminar Boards in New York and Atlanta, Council for Quality Growth, and Society of Women Engineers.

Ms. Bomar holds Bachelor and Masters degrees from the Polytechnic Institute of Brooklyn in Mathematics and Transportation Planning and Engineering, respectively. She also holds a Masters of Civil Engineering with a concentration in Transportation from Princeton University. She is the author of more than two hundred publications and studies. Ms. Bomar is listed in numerous Who's Who publications, including "Professional and Executive Women", in the "South and Southwest", "in the East", and "Among Community Leaders". Marsha was also a finalist for the 2003 Metro Atlanta and Gwinnett County Chamber of Commerce Small Business Person of the Year Awards. Street Smarts was selected in 2002 and in 2003 as an Atlanta Business Chronicle Pacesetter Company (one of only 50 for the whole Metro Atlanta region).

WALTER H. KRAFT

Walter H. Kraft is an internationally recognized transportation systems expert with over 40 years of “full cycle” experience in transportation including planning, design, implementation, integration, software, operations, management, and teaching. He has traveled extensively to Asia and Europe to view transportation facilities and lecture on Intelligent Transportation Systems in the United States. Dr. Kraft is employed by Parson Brinckerhoff, where he is President of PB Farradyne Engineering, P.C.; Senior Vice President of PB Farradyne Inc.; Director of PB Farradyne Inc.; and Vice President of Parsons Brinckerhoff, Quade and Douglas Inc. He is a registered professional engineer in 17 states.

Dr. Kraft is a Past-International President and an Honorary Member of the Institute of Transportation Engineers. He is a member of the National Steering Committee on Operations, which was organized by the United States Department of Transportation; a Fellow of the American Society of Civil Engineers; and a member of the National Society of Professional Engineers, Chi Epsilon, and Tau Beta Pi.

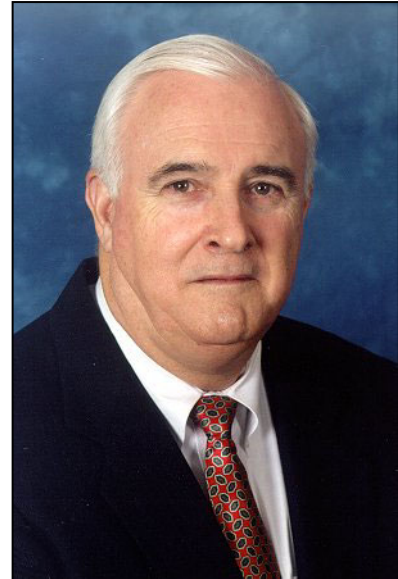
Dr. Kraft was graduated from the Newark College of Engineering with BSCE (1962) and MSCE (1965) degrees. He received the degree of Doctor of Engineering Science in 1975 from the New Jersey Institute of Technology.

Dr. Kraft has been involved with many community organizations including the Civil and Environmental Advisory Committee of the New Jersey Institute of Technology; the Economic Development Committee of the Township of Irvington, New Jersey; Board of Trustees of Overlook Hospital in Summit, New Jersey; and the Bicycle Safety Subcommittee of Union County, New Jersey’s Comprehensive Traffic Safety Program Task Force. He was on the adjunct staffs of Newark College of Engineering, the Polytechnic University of New York, and St. John’s University. Walter is a Certified Instructor of the National Highway Institute.

Dr. Kraft has received many awards including Metropolitan Section Robert Ridgway Award, ASCE, 1962; Special Service Award, MAUDEP, 1975; Frank Masters Award, ASCE, 1982; District One Distinguished Service Award, ITE, 1986; Ivor S. Wispart Transportation Engineer Award, ITE, 1986; Burton W. Marsh Award, ITE, 1992; Coordinating Council Award, ITE, 1997; Coordinating Council Award, ITE, 1999; and elected the 60th Honorary Member of ITE, 1999. He published many articles and books on various aspects of transportation. Most recently he co-authored the 495-page book on “Traffic Control System Operations – Installation, Operations and Management”, which was published by the Institute of Transportation Engineers in the year 2000.

WAYNE SHACKELFORD

Wayne Shackelford is Senior Vice President of Gresham Smith and Partners, an architectural, engineering and planning firm with offices in fourteen cities in eleven states. The firm has major planning, design, and construction activities in intelligent transportation systems at this time. Prior to this current position, he served as the Commissioner of the Georgia Department of Transportation from 1991 until his retirement in 2000. As Commissioner, he administered an annual budget of \$1.4 billion and managed the department's approximately 5,900 employees statewide. With those resources, he successfully provided the mobility that gave the world the opportunity to travel in Georgia during and after the 1996 Summer Olympic Games.



He brought a keen interest in customer service with him to the Georgia DOT. He nurtured the incident management and transportation management programs existing in the Department to bring them to a world-class level in time for the Centennial Olympics. The Department's Advanced Transportation Management System, *NAVIGATOR*, is a complete model of an urban transportation management system and is being studied by transportation leaders worldwide.

Mr. Shackelford has been active in both regional and national transportation policy development since he became Commissioner of the Georgia DOT. In 1993 he served as President of the Southeastern Association of State Highway and Transportation Officials (SASHTO), and in 1995 he was President of the American Association of State Highway and Transportation Officials (AASHTO). He served as Chairman of the Board of Directors of the Intelligent Transportation Society of America (ITSA) from May 1998 through April 1999 and was a member of the Board from 1996 to 2000.

Mr. Shackelford was Chairman of the Executive Committee of the Transportation Research Board (TRB), National Research Council in 1999 and has served on the Executive Committee since 1995. He served on the President's Council on Year 2000 Conversion as one of 21 professionals nationwide, from both the public and private sectors, invited to participate in this historical committee, where he represented surface transportation. He became Chairman of the Board of Georgians for Better Transportation in August 2003.

He has earned many national and state awards, including the Key Citizen of 1996 Award from the Georgia Municipal Association. In September 1997, the State Transportation Board bestowed their highest honor and dedicated the Transportation Management Center on Confederate Avenue as the Wayne Shackelford Building. In 2000 the Association of County Commissioners of Georgia created the perpetual Wayne Shackelford Excellence in Public Leadership Award and Mr. Shackelford was named the first recipient of this award. The American society of Highway Engineers chose Mr. Shackelford for the Robert E. Pearson, Person of the Year Award, in June 2001. The George S. Bartlett Award was presented by AASHTO, TRB and ARTBA to Shackelford in December 2001.

Following military service, Mr. Shackelford joined the University of Georgia Cooperative Extension Service, serving from 1959 through 1973. He was appointed Executive Assistant to the Gwinnett County Commission on January 1, 1973 where he managed the nation's fastest growing county for the next eleven years. From 1984 to 1991 he held executive positions with two major development companies.

GARY K. TRIETSCH

Gary Trietsch is the District Engineer for the Houston District of the Texas Department of Transportation (TxDOT). The district comprises six counties: Brazoria, Fort Bend, Galveston, Harris, Montgomery and Waller. He was named District Engineer of the Houston District in September 1995.

Mr. Trietsch joined TxDOT's Fort Worth District Tarrant County construction section in 1967, working summers and part time while attending the University of Texas at Arlington. After earning his bachelor's degree in civil engineering in 1970, he moved to the design section. From 1972 to 1978, Mr. Trietsch worked in the district traffic engineering section, earning his master's degree in civil engineering from the University of Texas at Arlington in 1974. While working in various design capacities in the Fort Worth District from 1978 to 1987, Mr. Trietsch became Assistant District Design Engineer in 1985.

Moving to Austin in 1987, Mr. Trietsch became director of the safety and traffic operations section in the Safety and Maintenance Operations Division. As Assistant Division Director for Traffic Operations in 1988, he was responsible for the central permit operations, traffic safety, traffic engineering and traffic management systems sections in the Maintenance and Operations Division. In 1992, Mr. Trietsch was selected as director of the division.

Honored for his contributions in the field of engineering and to the state of Texas, Mr. Trietsch received the 1991 Dewitt C. Greer Award from TxDOT, the 1996 Transportation Engineer of the Year award from the Texas Section of the Institute of Transportation Engineers, and the 1997 Dr. L. I. Hewes Award from the Western Association of State Highway and Transportation Officials (WASHTO).

Mr. Trietsch was the Founding President of Intelligent Transportation Systems (ITS) of Texas in 1993. He is also a member of the Institute of Transportation Engineers and the National Society of Professional Engineers.

THOMAS C. WERNER

Thomas C. Werner was appointed Regional Director for the New York State Department of Transportation's eight-county (population of one million) Capital District region in May 1998 after having served nine years as Director of the Traffic Engineering and Highway Safety Division in Headquarters. As Regional Director, he oversees 1,000 employees and a \$100 million annual capital construction program.

Mr. Werner currently serves on the AASHTO ITS Standards Development Oversight Committee for the Subcommittee on Advanced Transportation Systems and is a member of the FHWA Work Zone Senior Working Group.

Mr. Werner began his state career in Buffalo in 1965 serving in various positions in the Regional Planning, Design, Construction, and Traffic Safety offices. He accepted a promotion to the Albany Main Office in 1975 where he was involved in all phases of development and implementation of the INFORM system on Long Island – an early example of successful ITS deployment. He attended Canisus College in Buffalo, NY and graduated from the University of Detroit with a BSCE degree. He also obtained an MBA degree in Management Science from SUNY/Buffalo.



He has been active in other national and regional organizations including TRANSCOM, I-95 Corridor Coalition, Transportation Research Board, and the American Association of State Highway and Transportation Officials (AASHTO) where he served as Vice-Chairman of the Standing Committee on Highway Traffic Safety. He also served as Panel Chairman to NCHRP Project 7-13 "Quantifying Congestion" and on the FHWA Expert Panel for Operations and Maintenance of Traffic Control Systems.

JAMES WRIGHT



James Wright is currently an on-loan executive from the Minnesota Department of Transportation to the American Association of State Highway and Transportation Officials. He is providing executive leadership from the national 511 Coalition, the ITS Standards program, and ITS America initiatives. Immediately prior to this assignment, he served in the role of Division Intelligent Transportation Systems (ITS) Engineer for the Minnesota Department of Transportation's Metropolitan Division. His responsibilities were ITS planning, regional deployments, and national and international liaison.

He has been active in ITS since 1991. From 1991 to 1996 he directed the Minnesota Guidestar Program that is a statewide ITS effort. From 1996 to the present he has directed the Orion "Model Deployment" program. During these years he has delivered \$100 million in ITS work.

Key achievements include: 1) development of creative procurement processes for public/private partnerships resulting in \$10 million in private investments, 2) development and completion of 12 ITS field trials, 3) development of over 15 ITS project managers who are continuously being recruited throughout the nation, 4) establishment and management of the statewide ITS organizational structure, 5) presentation at every ITS America Annual meeting and the ITS World Congresses, 6) conducting some of the first statewide customer surveys for ITS, and 7) introduction of ITS into rural areas.

National and international liaison is a key role of Mr. Wright's responsibilities. Specific activities included US Congressional liaison, USDOT liaison and international liaison. The US Congressional liaison was instrumental in bringing \$40 million into MnDOT's ITS program. An additional \$10 million in private investments were brought into the program through strategic alliances.

Mr. Wright served as Chair of ENTERPRISE (consortium of states with emerging ITS initiatives) and as an at-large member of ITS America Coordinating Council. He is currently serving as Chair of AASHTO/ITE Traffic Management Data Dictionary; Chair of ITS America Advanced Traffic Management Systems Committee; Vice Chair of the ITS America Coordinating Council; and is the AASHTO representative for the World Road Congress.

Prior to his ITS activities Mr. Wright spent five years developing the department's computer aided design systems, five years in planning where he directed special studies in energy and financing. He spent one year working with the legislature on transportation energy policy development. He also has ten years construction and design experience.

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ASSESSMENT OF AND RECOMMENDATION FOR THE PHYSICAL SECURITY AT TRAFFIC MANAGEMENT CENTERS

by

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Wayne Shackelford
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Course Instructor

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Prepared for

CVEN 677

Advanced Surface Transportation Systems

Department of Civil Engineering
Texas A&M University
College Station, TX

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SUMMARY

The purposes of this report were (1) to assess the current state-of-practice on transportation/traffic management center (TMC) security in the United States, and (2) to then provide recommendations as to what is needed to ensure that appropriate security measures are taken at TMCs. The author focused his research efforts on exploring the security measures against physical attacks on TMCs.

A survey was administered to TMC operators at 22 TMCs in 14 different states in the United States. The responses helped establish the current levels of security used at TMCs in the United States. The answers to the surveys were then used to generate recommendations for minimum requirements needed at TMCs in the United States for the safety of the facilities and the personnel. The final recommendations in this report are a revised set created from the first group of recommendations and the comments of TMC operators who reviewed the first recommendations.

The general finding in this report was that all TMCs have varying levels of security, but overall, they all appear to be adequate. The current security levels are considered adequate based on the perception of TMC operators that their facilities are not in danger of being physically assaulted. The author believes this to be an accurate assessment given current threat levels associated with TMCs. These threat levels are influenced by the following components:

- Size of the facility (including the number of personnel);
- Functional impact of a TMC on roadway operations;
- Functional impact of a TMC on emergency management; and
- Location of a TMC (e.g. on a military base or in a large metropolitan area have higher threat levels than on a rural roadway).

Consequently, the author of this report believes that: (1) the TMC security requirements should be based on the perceived threat; and (2) there are certain improvements to security at TMCs that should be implemented.

The author has summarized the fourteen specific recommendations discussed in this report into the following three primary suggested improvements with respect to TMC security:

1. All TMCs should be designed and constructed (or retrofitted in the case of pre-existing structures) under the “weakest link” philosophy, such as:
 - a. Minimize the use of windows and design facilities with the understanding that windows are structural components in any building and not just an entry for light; and
 - b. Design and build the TMC operations center and equipment into the center of the facility (outer offices and hallways become buffer zone to absorb debris from a natural or a man-made disaster);
2. All TMCs security should be designed based on the expected “threat” associated with a TMC (e.g. natural disaster, man-made disaster, power failure); and
3. All TMCs systems should be designed with redundancy; they should be protected both physically and electronically; and they should be monitored for physical or electronic intrusion.

It should be noted that the specific TMCs contacted by the author are not mentioned in the report for security reasons, but it can be stated that only “large” TMCs in the United States were contacted. A large TMC is a facility that has a wide range of capabilities (e.g., incident detection and management, control traffic signals, emergency management, etc.) and/or monitors numerous transportation facilities.

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INTRODUCTION

Background

In many of cities in the United States the roadway infrastructure is approaching capacity. As United States economy continues to grow, so will its need for added roadway capacity. In the past, the solution to increasing capacity was adding more roadways and widening preexisting roadways. The advent of various intelligent transportation systems (ITSs) has further increased capacity by optimizing throughput movements, such as implementation of traffic actuated signals (1,2).

The most recent tool for transportation engineers is the development of transportation/traffic management centers (TMCs). There are numerous TMCs throughout the United States. While they are rarely identical, they all serve a similar purpose and that is to monitor their respective traffic flows and to manage those flows through technology, experience, and protocol. TMC operators measure real-time traffic volumes on roadways and they relay traffic information that allows motorists to make informed travel decisions. For instance, if a crash occurs on a freeway, a TMC operator(s) inform the applicable authorities (police, fire, HAZMAT, and/or tow truck companies) and the road-users. The operators use variable message signs (VMSs), highway advisory radio (HAR), and/or web sites to communicate with the motorists. Informing roadway users to closers, crashes, and other events that may impact traffic flow is one way to protect the capacity of roadways. With regard to crashes and other movable roadway obstructions, the quicker that the applicable authorities arrive on the scene to access and respond to the situation the more rapidly that the original traffic flow conditions can be reestablished. In summary, TMCs are an asset for transportation engineers to utilize as they work to optimize the transportation infrastructure to squeeze every ounce of capacity that is theoretically available.

While there are various scales of TMCs throughout the United States, the size and operability of each one is based on the perceived need of their specific coverage area. Regardless of whether this perceived need is under- or overstated, security should always be in the minds of those who operate the TMCs and in the minds of those who use the information generated by the TMCs. The level of concern associated with TMC security has been different across the nation; however, after September 11, 2001 protection of the transportation infrastructure and its respective facilities, such as TMCs, has polarized as a key topic in transportation in the quest for improving homeland security in the United States (3).

The protection of TMCs is an issue with two primary layers. One level is the defense against “soft-attacks”. A soft attack of a TMC would consist of an assault on the technological systems through the means of a computer virus or external operationally override. This form of strike against a TMC may disrupt regular traffic flow, and depending on the extent of control of the TMC and its designated default settings and safeguards, the strike could result in minor congestion or an overall shutdown of regular operations of the affected systems. A “hard-attack” is another area that should be considered when designing and operating a TMC. This form of strike would consist of the physical destruction or the taking physical control of a TMC.

Problem Statement

The defense of the transportation infrastructure in the United States is essential to the vitality of the social and economic well-being of the country. As transportation agencies work to optimize the flow of traffic on roadways, TMCs are rapidly becoming a vital tool used by transportation engineers to maximize the capacity of the current systems in place and yet to come. Consequently, the impact that TMCs have on the transportation infrastructure is increasing. It is believed that as both the role and responsibility of TMCs continue to expand that the likelihood of an attack on a TMC will also grow. Research should be conducted to study the physical security at TMCs in the United States. Security at TMCs is a broad topic, and so, the author limited his investigation to the defense of TMCs from hard-attacks.

Objectives

The author established the state-of-the-art with regard to the physical defensive measures at TMCs in the United States and recommended a set of general guidelines that should be instituted to ensure the appropriate physical defense of any TMC. The following is a list of objectives that the author followed for this study:

- Assess the current state-of-the-art with regard to the physical defense of TMCs in the United States;
- Summarize concerns associated with the current practice;
- Generate a list of recommendations for the essential ingredients in the physical defense of a TMC;
- Test these recommendations by having them critiqued by current TMC practitioners; and
- Generate a final list of recommendations for the essential ingredients in the physical defense of a TMC.

Scope

This report contains the recommendations to preexisting TMCs and to local, state and federal agencies in the design of future TMCs that would better enable them to make informed decisions with respect to the physical defense against hard-attacks. These recommendations are based on the comments from surveys submitted by large TMCs. Large is a relative term that can relate to various different aspects of a TMC; however, the overall functionality and the magnitude of the impact of the destruction or capture of a TMC will define whether a TMC is large or not. Navigator, TransGuide, TranStar and the Smart Traffic Center in Virginia are good examples of the size of TMC that were contacted. The goal of the author was to contact twenty large TMCs in at least five different states in the United States.

SURVEY

In this section of the report, the author discusses the surveys that were used in the collection of data. Personnel from each TMC that offered to supply data was first contacted by phone and asked to participate in this study. Each phone conversation was immediately followed by a state-of-practice survey (See Appendix A). Each TMC participant responded to nine questions that focused on security concerns at TMCs. Twenty-two TMCs were contacted and nineteen TMCs responded to the state-of-practice survey.

Security concerns were subdivided into four tiers of defense and the questions were very specific within each tier. The four tiers are as follows:

- “First-Tier” - the physical grounds surrounding the building and includes fences, bollards, security patrols, and cameras;
- “Second-Tier” - the exterior of the building, such as additional cameras, non-flammable walls and unique access codes for all personnel to enter and exit the building;
- “Third-Tier” - the internal security within the facility, and it consists of cameras, unique access codes, security patrols, internal tracking; and
- “Fourth-Tier” - the non-physical defense of the facility that incorporates defense against cyber-attacks on the TMC software systems and the protection of communication lines.

All of the responses from the survey were used to develop recommendations that if implemented by TMCs in the United State would help establish at least the minimum security perceived as essential to the defense of TMCs against hard-attacks.

These recommendations were formatted into a second survey that was sent out to all of the TMC participants from the first survey. There were twelve recommendations and each respondent was asked to

state whether he/she agrees, partial agrees, or disagrees with each recommendation. In addition, everyone was to rank on a scale from 1 to 3 (3 being the highest) his/her particular TMC against the recommendation regardless as to whether he/she agrees with each recommendation. Summary comments were also encouraged, especially if the respondent agreed with the recommendation but his/her particular TMC did not rank high. This survey is also in Appendix A. Eleven out of the twenty-two TMCs that were contacted responded to the second survey.

RESULTS

The findings of both surveys are tabulated and summarized in this section of the report.

State-of-Practice Survey

Every TMC that responded to the survey has some degree of security. Thirteen out of eighteen (72 percent) TMCs have first-tier defenses and ten out of eighteen (56 percent) have fourth-tier defense. All of the TMCs have second- and third-tier defenses.

First-Tier Defense

First-tier defense is the first level of protection against hard-attacks. Only fourteen of the nineteen TMCs (74 percent) that responded to the survey have some level of first-tier defenses. Thirteen of the TMCs with first-tier defenses have fences along the perimeter and the fourteenth TMC has bollards (see Figure 1 and 2). Of the fenced facilities, eight have gate guards and five have unique access codes (one TMC has both). Six of the fenced facilities and the one facility with bollards only have some form of guards patrolling the grounds. Two of the fenced TMCs have cameras on the fences monitoring the entrances to the grounds surrounding the TMC. Figure 1 and 2 contain images of some of the various security measures discussed above, and Figure 3 contains a breakdown of the findings with regard to first-tier defenses from the state-of-practice survey.

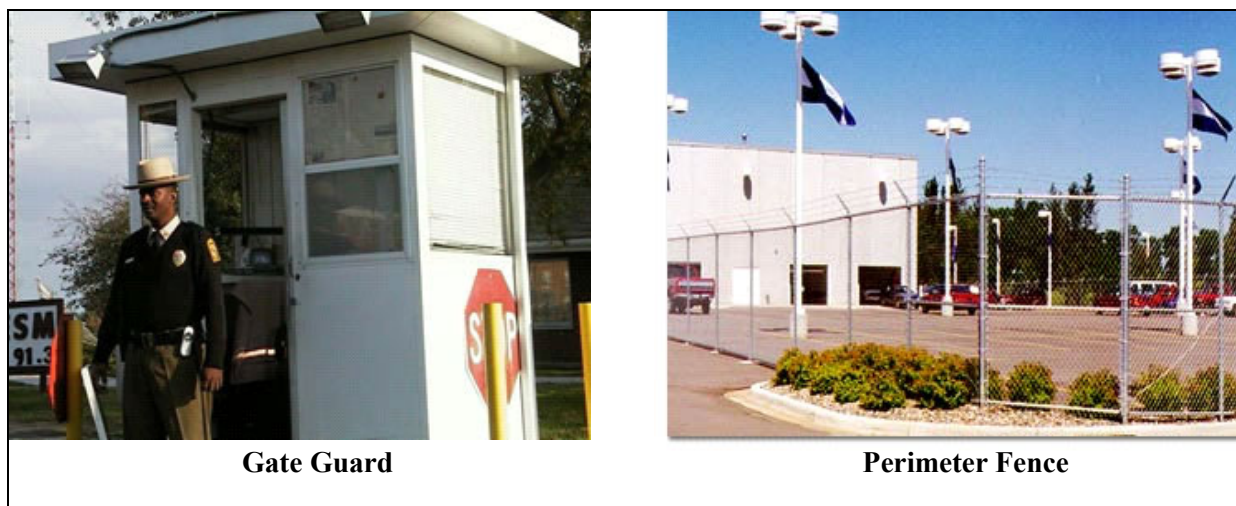


Figure 1. First-Tier Defenses (4,5)



Figure 2. First-Tier Defenses (6)

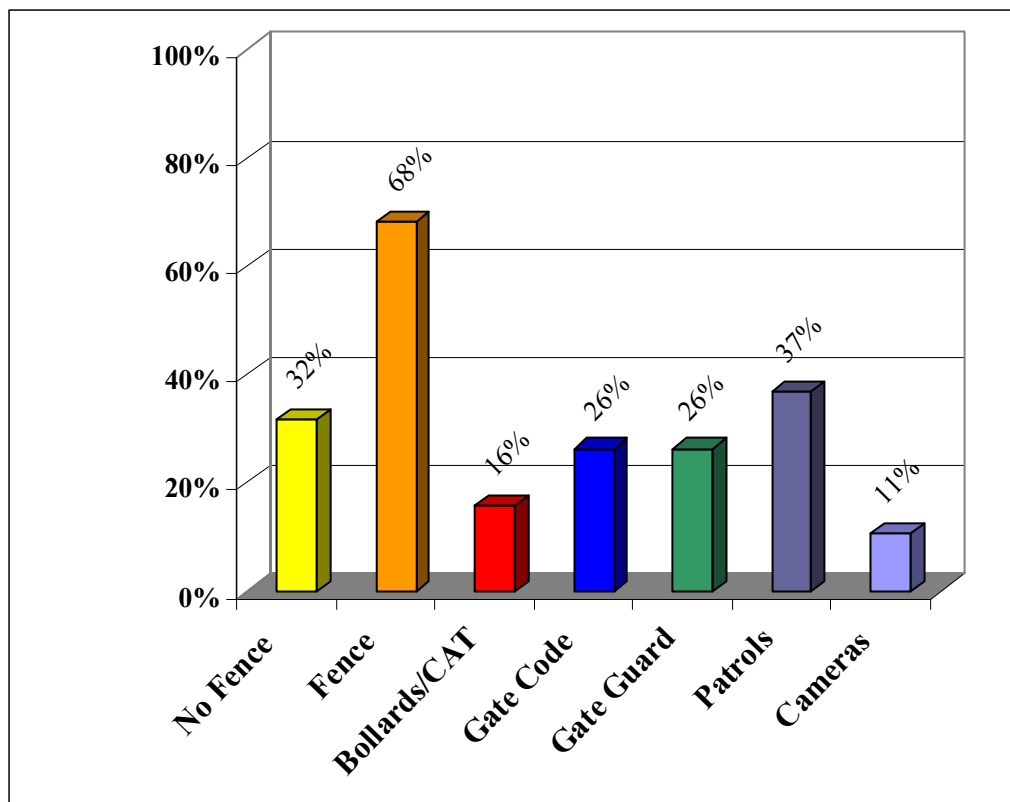


Figure 3. First-Tier Defenses of TMCs in the United States

Second-Tier Defense

Second-tier defenses relate to the security that goes into the physical exterior of a TMC facility. The only factor that all but one of the TMCs incorporate into their facility is that access is controlled with at least some form of coded card that is unique to its respective person (see Figure 4 and 5). These cards grant entry into the facility either through proximity detection or card readers. Currently, none of the facilities

use biometric readings (e.g. finger prints, voice recognition, and retinal scans) for security purposes (see Figure 4).



Figure 4. Electronic Access Control (7,8,9,10)

One thing that was not determined from the data collected in the survey was the physical mechanism that barred entry at access points. For instance, one person through a phone interview prior to the survey discussed the use of magnetic locks at his facility. This is one of the common methods for providing building security. The only concerns with these systems are with the loss of power and/or in the case of a fire. In the case of fire, magnetic lock systems are designed to disengage. One of the questions that developed after the initial survey was whether the facilities had physical latching mechanisms for the doors to maintain security during the interruption of power to the magnetic locks. All other second-tier security measures at TMCs varied among facilities.

Some of the variation in the responses by the TMC operators resulted from either a misunderstanding in the amount of detail requested in the survey responses and/or the concern of the respondents as to providing sensitive information that could be compromised if documented. For instance, one respondent reported having non-flammable walls. Based upon the survey results, it was determined that at least one other facility had non-flammable walls.

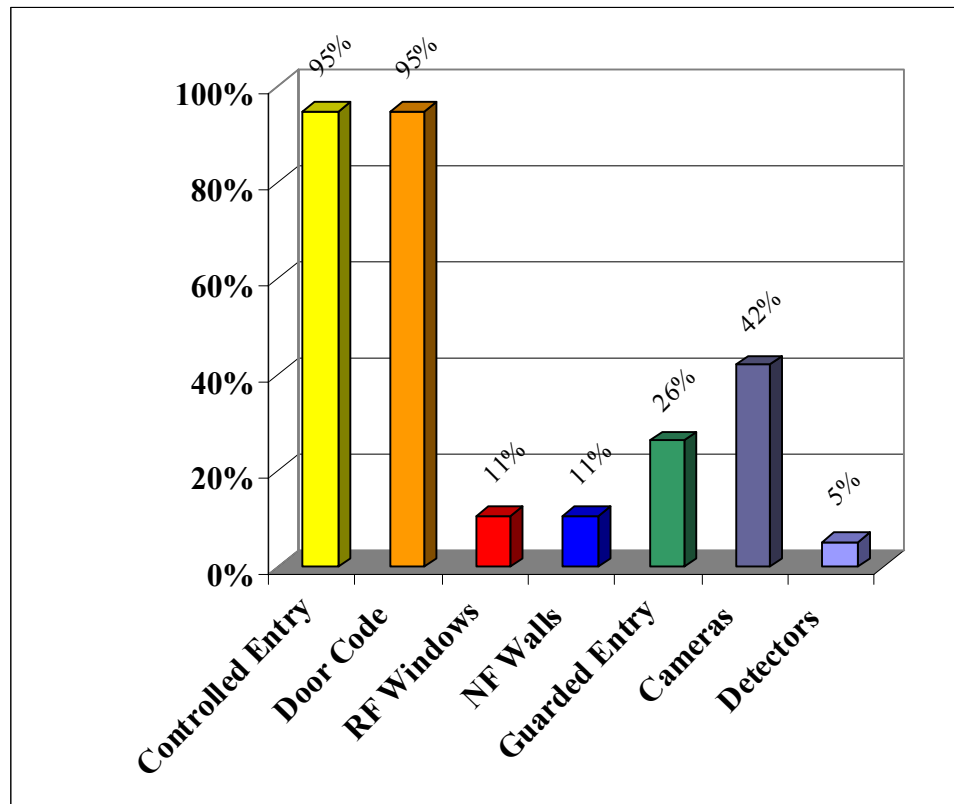


Figure 5. Second-Tier Defenses of TMCs in the United States

Another statement made by one TMC operator was that his facility had security lighting. The author, having visited at least one other facility, is certain that security lighting is present at other facilities; however, he can not confirm on the exact number of facilities with security lighting given the survey findings. Figure 6 is a photograph of one form of security lighting that comes equipped with a motion activated camera system. Unfortunately, this information was not addressed in a manner in the survey as to illicit responses.



Figure 6. Security Lighting System (11)

On the other hand, the author did specifically request information related to the layout of windows on the exterior of the facility and whether the windows were reinforced and/or bulletproof. Only two of the nineteen facilities (11 percent) reported having reinforced windows, and no other responses with regard to windows were provided. While this is entirely possible, the author believes that this is not representative of TMCs in the United States, and that the specific use of windows and the limitations of the windows are integral to the security of TMCs (12). In particular, the author was concerned as to whether each TMC

had windows on the first floor or not. This information should not have been considered critical because it would be obvious whether there were external windows. Consequently, either the question was misunderstood or respondents forgot to answer that portion of the question.

The most sensitive data provided with regard to TMCs were related to monitoring the exterior of the building. The access cards have already been discussed. Other surveillance methods used by some of the TMCs surveyed include:

- Guard Patrols (2 out of 19 or 11 percent);
- Video Cameras (8 out of 19 or 42 percent); and
- Passive Window and Door Sensors (1 out of 19 or 5 percent).

Video surveillance and access cards are the primary means of monitoring the security of TMCs surveyed. This is a good practice because the two methods allow for tracking and increase monitoring efficiency (i.e. one or two individuals can monitor an entire facility and dispatch security as needed and to specific locations).

Passive sensors on doors and windows are another means of monitoring a facility's security. The main benefit of these sensors is that they further decrease the amount of personnel necessary to monitor a building. The monitoring equipment for these sensors could be placed in the video surveillance room and a two or three person staff could observe the entire TMC and direct any internal security to areas of concern such as a breach in security. Figure 7 contains various images of second-tier defenses with regard to monitoring equipment and security personnel.

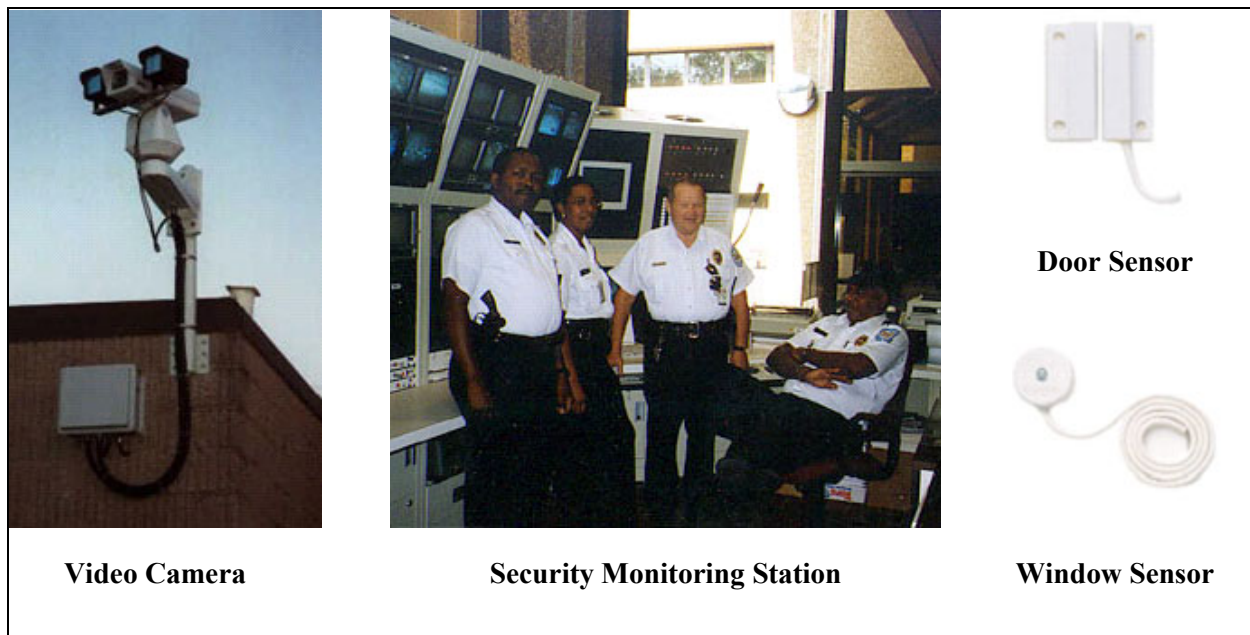


Figure 7. Video Surveillance and Passive Monitoring (13,14,15)

Guard patrols, while helpful as a deterrent and good for rapid response, were not seen as essential to the safety of TMCs. This is the assessment of the TMCs based upon the limited use of patrols as mentioned in the survey results. One of the TMCs is co-located at a military installation and guarded patrols were added after the tragedy on September 11, 2001. Hence, a TMC may need added security as its respective

threat level increases. This threat level will increase if TMCs are co-located with other prime targets, such as a military installation.

Also, the threat level will increase as TMCs increase in their functionality. A TMC that is co-located with law enforcement and an office of emergency management (OEM) could impact a city's ability to respond to a disaster if destroyed, or it could impact a city if captured and used to disseminate poor intelligence to confuse the public. The later is less likely in the case of a terrorist attack because terrorists traditionally seek to inflict the maximum amount of damage with minimal effort. The orchestration of seizing a poorly guarded TMC and being able to operate its systems in a manner to disrupt the public enough to cause a catastrophe would be far more involved and harder to conceal than the destruction of a TMC (16).

Third-Tier Defense

Internal defense is the next level to the security of any facility. Internal security starts with whether a facility is shared with more than one entity. Even if the different entities share common interests such as TMC operators and local law enforcement, internal security should start with who is in the building. For example, TMCs that co-locate with law enforcement could contract the law enforcement to establish and monitor security issues within the facility. Out of 19 TMCs, 7 (37 percent) centers share their building with law enforcement. The data collected do not state the level of involvement that law enforcement may have in the security matters of the TMC; however, it is the belief of the author that the law enforcement officials would at least mention any concerns with regard to TMC security that might negatively impact their own internal security. Figure 8 below is a graphical representation of the findings from the survey.

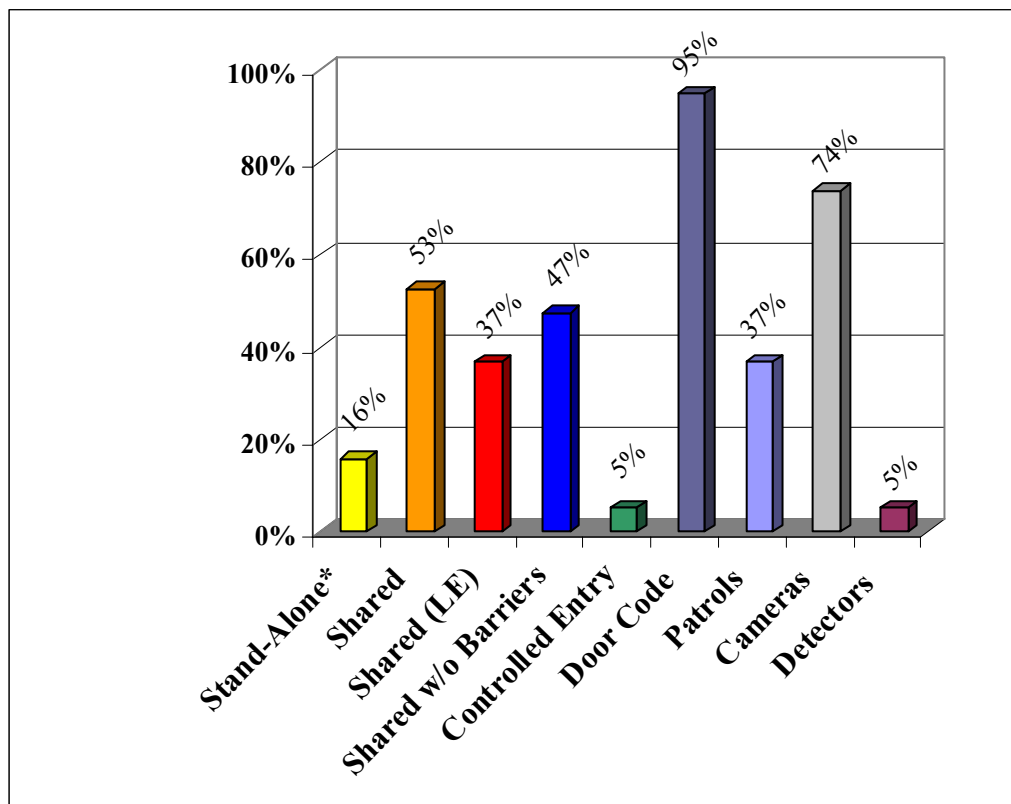


Figure 8. Second-Tier Defenses of TMCs in the United States

One interesting finding was that the facilities co-located with law enforcement and the facilities with internal guards did not overlap as much as the author would have expected. Only two of the seven TMCs (27 percent) with internal guards have local law enforcement, but only one TMC operator reported using law enforcement for security. That facility has state highway police (SHP) monitoring the entrance into the TMC, and the SHP also review the building security once a month with the TMC operators.

Internal video surveillance and motion detectors are two other means to establish security within a building. A majority of the TMCs, 14 out of 19 (74 percent) observe movements within the facility with video equipment, while only one (5 percent) TMC uses motion detectors. That one TMC actually uses both cameras and motion detectors. Figure 9 depicts a common internal closed-circuit television camera (CCTV) and a common motion detector.



Figure 9. Video Surveillance and Passive Monitoring (11,17)

Fourth-Tier Defense

The fourth-tier defense is a little more abstract than the first three tiers in that it deals with system redundancies in the loss of the facility or some of its systems. This defensive line is more for mitigating, if not, negating any damage caused to a TMC in an attack. These system redundancies are also necessary for in the case of facility losses as a result of adverse weather conditions. System redundancy refers to both the software and hardware, internally and externally. Various TMCs have backup software if the system crashes and some have backup facilities. Also, some centers have alternate communication lines to their equipment in the field. The general findings are presented in Figure 10.

One area of redundancy that at least one TMC is leading in is power and support backups. This facility has at least one hour of battery backup and more than seven days of generator power. Furthermore, there is on-site drinking water for the operating personnel. This facility also has extended communication lines that include wireless, radio and telephone. The TMC and the OEM that is co-located with it can operate in adverse weather conditions to help with traffic operations through monitoring and dissemination of information when most local residents would have to leave the area.

The only real defense in the fourth-tier deals with system protection from computer hacking. This was not within the focus of the report, because it is considered a soft-attack; however, the author recommends further research in the development of firewall software and computer intrusion monitoring software.

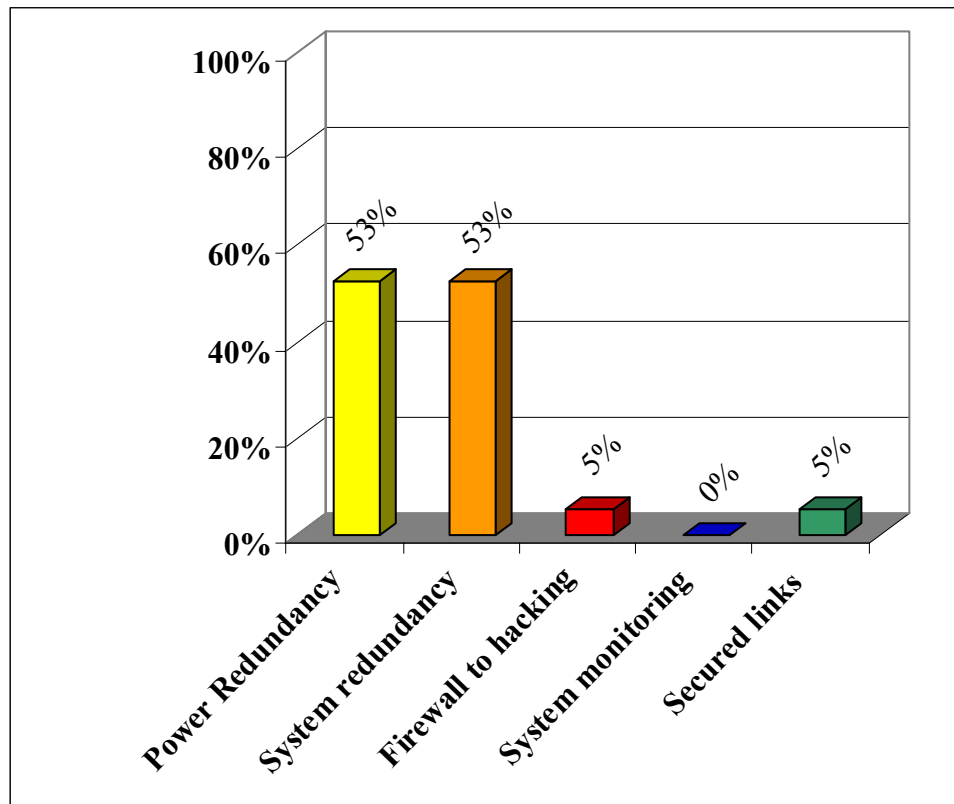


Figure 10. Fourth-Tier Defenses of TMCs in the United States

A tabulated data summary of the state-of-practice survey is in Appendix B.

Recommendation Survey

The recommendations generated by the author were based upon the comments from the state-of-practice survey, and then, they were redistributed to the nineteen TMCs that responded in the first survey. Below are the paraphrased versions of the recommendations (see Appendix A for the exact wording).

1. Fenced perimeters and crash abatement devices are needed.
2. Reinforced, non-flammable material should be used primarily in the structure.
3. Minimal glass should be used in the exterior and the glass should be reinforced. The use of glass on the first floor should be avoided.
4. Access to the facility should be monitored and kept to a minimum.
5. External windows should be permanently fixed (can not be opened).
6. Access within the facility should be monitored and zoned (personnel only have access to areas that are essential to do their assigned tasks).
7. Closed circuit television cameras should be used to monitor internal security.
8. Internal windows should be permanently fixed (can not be opened).
9. TMCs should be co-located with law enforcement.
10. Redundancy should be built into the primary TMC control systems (e.g. backup power supply and alternate remote operation systems).
11. Computer and communication lines should be monitored and protected against unauthorized access.
12. Redundant systems should have protection from unauthorized access (e.g. password protect any remote operation functions).

The responses to the recommendation survey varied. All of the recommendations are either partially or completely agreed with by ten or more (91+ percent) of the respondents. Figure 11 is a graph of the responses to each recommendation. Eleven of the nineteen TMC operators that responded to the first survey responded to the recommendation survey. All TMC operators agree that access to the facilities should be controlled and monitored, redundancy should be integrated into their systems, and both computer and communication lines should be monitored and protected against unauthorized access.

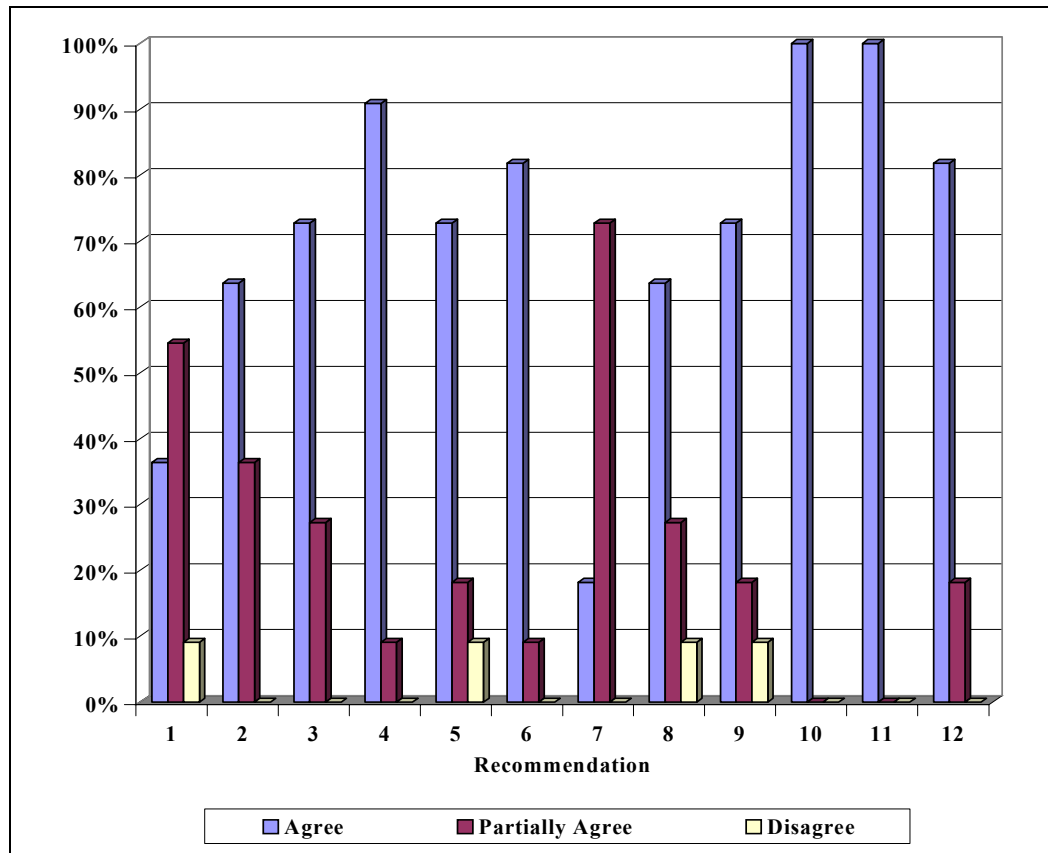


Figure 11. TMC Recommendation Acceptance

The most controversial recommendations are 1, 5, 7 and 8 that correspond with establishing fenced perimeters, limiting window use and making all windows non-operable (cannot open). No direct comments were made with regard to concerns for recommendation number 1 on fencing the perimeter; however, it is the belief of the author that some of the TMC operators do not see their facilities as likely targets for destruction or attack. Hence, they do not feel it is essential to have a fenced perimeter and crash abatement devices. One person half-jokingly responded that the only solution is to place a moat around the TMC. While this was neither a literal or practical suggestion, the author thinks that TMC operators are aware that there is a practical level of security that is achievable and anything above that is not a proper solution. The question is, "What is the bar that should be set?"

The respondents made an excellent point with respect to recommendations 5 and 8 on facility windows. Windows are commonly used as egress points in the case of emergency. No one responded that limiting the use of windows was a poor recommendation, only that some windows may require the ability to be opened. One TMC operator suggested the use of security sensors on all windows that may need to be opened. Another individual stated that the windows allow for light to come into the facility to make for a more pleasant environment for the employees.

The last controversial recommendation deals with the need for cameras for internal monitoring. While 100 percent of the respondents either partially or completely agreed with the recommendation to use cameras to monitor the interior of a TMC, 82 percent (9 responses) of the TMC operators only partially agreed to the recommendation with one operator stating that the internal use of cameras to monitor hallways and stairwells would be “overkill”. The best argument made was that the use of internal monitoring equipment should be based upon the size of the facility. For example, if there is a small TMC with just a lobby and a control and equipment room, then external cameras and access monitoring is probably all the security required with respect to protection against hard-attacks.

Based upon the responses to the other recommendations, all (10 completely agree and 1 partially agrees) of the facility personnel believe that access control and monitoring will ensure their physical safety. Furthermore, 11 TMC operators (100 percent) completely agree that redundancy of the TMC key systems is important, and 9 operators agree and 2 partially agree (combined is 100 percent) that these systems are more susceptible to external tampering through computer hacking or splicing into external hardware. Consequently, they believe that the system itself is more vulnerable to external soft-attack than the likelihood of the facility being destroyed or captured in a hard-attack.

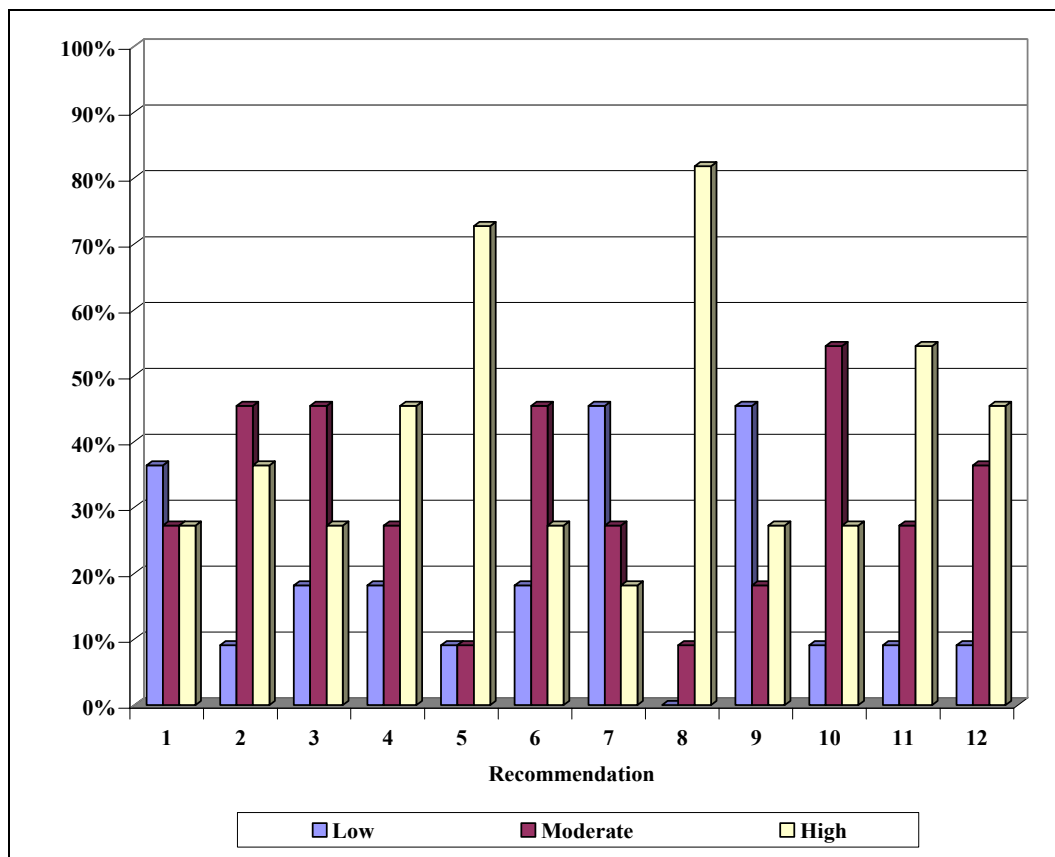


Figure 12. TMC Recommendation Compliance

One other aspect to the recommendations survey was the request for respondents to assess their own facility against the recommendations regardless of whether they agreed with them (see Figure 12). An interesting finding was that recommendations 5 and 8 with regard to making all windows non-operable, two that received opposition in some form, had the most compliance. External windows were not able to be opened in 9 facilities (82 percent), and 10 facilities (91 percent) had windows internally that could not be opened. The other recommendations showed differing levels, but the written comments conveyed that

those facilities that supported the recommendations but had moderate to low compliance, were in the process of upgrading their facilities.

RECOMMENDATIONS

This section contains a summary of the recommendations and a detailed revised list of recommendations generated by the author from the given survey response discussed in the previous section of this report. While the author has revised the original twelve recommendations listed in the recommendations survey, he believes that the following are the three primary recommendations that should be implemented by all TMCs:

- All TMCs should be designed and constructed (or retrofitted in the case of pre-existing structures) under the “weakest link” philosophy, such as:
 - Minimize the use of windows and design facilities with the understanding that windows are structural components in any building and not just an entry for light; and
 - Design and build the TMC operations center and equipment into the center of the facility (outer offices and hallways become buffer zone to absorb debris from a natural or a man-made disaster);
- All TMCs security should be designed based on the expected “threat” associated with a TMC (e.g. natural disaster, man-made disaster, power failure); and
- All TMCs systems should be designed with redundancy; they should be protected both physically and electronically; and they should be monitored for physical or electronic intrusion.

The author will define two key words mentioned above: weakest link; and threat. Weakest-Link is a term that the author uses to describe a design principle that designers use in the layout of a facility and in the selection of materials for a facility. This principle states that a facility is only as strong (structural sound) as the weakest member in the structure. In the case of TMCs, it is the belief of the author that this would be the windows for all of the facilities, but TMC operators should individual study their own buildings for the weaknesses of the structure. Part of safety is designing a structurally sound building but all things built by man have a weakest point, and that weakest point will define the overall structural integrity of a facility.

Threat is a term used by the author to describe the level of security risk that may be associated to a building. The threat is believed to increase based on the following components:

- Size of the facility (including the number of personnel)
- Functional impact of a TMC on roadway operations
- Functional impact of a TMC on emergency management
- Location of a TMC (e.g. on a military base or in a large metropolitan area have higher threat levels than on a rural roadway)

The remainder of this section includes more specific recommendations and the final revised recommendations generated from the responses to the recommendations survey. For instance, there are various issues specific to facility access, but it is recommended to keep access points to a minimum. Access is both a safety and security issue in that designers should minimize access to heighten security, but guarantee a proper level of access to facilitate egress in the event of a catastrophe such as a fire.

It is recommended to TMCs to use a minimal number of windows on the first floor and that the windows themselves should be small and fixed (cannot be opened). In addition, only essential windows should be designed to open. All windows that can be opened should be monitored by motion and/or contact sensors.

One of the primary reasons for minimizing the use of windows is that windows can fail. They can break in at least three ways: (1) in sheets (the entire pane of glass), (2) large shards (fragments of glass), or (3) small shards, and all three methods will endanger any living thing in the path of the glass. Hence, it is recommended that:

- All use of glass should be kept to a minimum (both on the exterior and the interior);
- Windows with improved strength and breakage characteristics should be used (the author recommends to the reader to read the article “Emerging Uses of Window Glass” for a comprehensive look at the use and ability of glass and some of the common misunderstandings associated with glass) (12,18); and
- Internal walls around key operation and equipment areas should be designed to absorb flying debris.

While both the walls and the windows could be designed to withstand the destructive forces of man-made explosive ordinance and/or impacts, this is not the intent of the author. It is the belief of the author that the attempt to destroy a TMC is highly unlikely. In addition, every structural design has its limitations. If you design a building to withstand a certain amount of explosive, doubling that amount of explosive will probably destroy it. However, after speaking to one prominent structural engineer and professor, Dr. Beason at Texas A&M University in College Station, Texas, it is the understanding of the author that there are some fundamental design principles that could be used to better equip the integrity of a building. Under the principle of the weakest-link philosophy, a comment by Dr. Beason is that if reinforced windows are used, but they are not properly anchored, the window may fail as a solid pane of glass and injury building occupants. All of the facility walls, windows and doors should be properly anchored and of similar strength (12,18).

Along the lines of shared facilities, there should be some level of separation among different entities, especially if the various organizations involved do not have similar vested interests. These barriers would most likely be in the form of restrictive walls and doors. The doors would probably require an access card or key. With modern module office spaces, additional precautions may be necessary such ensuring solid walls from the floor to the ceiling (not the acoustic tile or ventilation which allow for crawl spaces, but the solid bottom of the next floor above or the roof of the structure). All facilities surveyed use access cards. The use of access cards further promotes internal security monitoring and the access throughout the TMC can be zoned. In other words, personnel access can be limited to their respective work areas and their movement can be monitored. If a perpetrator was able to appropriate an access card and tried to enter a room that was not authorized, this could register as a warning to dispatch internal security. Two TMCs even have card access readers to the stairwells and elevators. Eight facilities do not have restrictive walls, but five of the eight either are co-located with law enforcement or are stand-alone buildings.

Revised Recommendations

When applying each of the following recommendations, management should assess the needs of a TMC facility based upon the buildings size and purpose, if it is built or new construction, and whether the building is shared with another entity. Furthermore, the first recommendation is only necessary if the facility operators perceive a high likelihood that the facility will receive a hard-attack. Of all of the recommendations below, the first one should also be the easiest to retrofit to a facility, should the threat level be increased. The recommendations will be broken down into the different defense tiers.

First-Tier Defenses (Perimeter Security)

1. The perimeter of the TMC should be fenced on at least three sides with a non-flammable material (e.g. wrought iron or masonry).
2. All perimeter lines that are not fenced and/or have long tangents perpendicular to the facility perimeter (long tangents would allow for ramming velocities) should have bollards or other crash

abatement devices installed along these key locations that might permit a perimeter breach by a vehicle.

Second-Tier Defenses (External Building Security)

1. The facility exterior structure should be constructed primarily of reinforced, non-flammable material (e.g. masonry).
2. Minimal glass should be used on the exterior of the TMC. All glass used on the exterior should at least be designed to handle the loads of the most adverse weather conditions unique to the location of the TMC (e.g. tornados, hurricanes, etc.). If possible, glass should only be used on the second floor of the exterior or higher. If glass is used on the first floor, it should be used for internally lighting conditions, and it should be narrow (as to not allow as an alternate entry point) and placed as high as possible on the exterior wall.
3. External windows should only be designed to open if they are used for emergency exits and/or essential access points to facility operations.
4. All external windows and doors should be fitted with sensors to monitor access. This will be easiest for new construction and smaller facilities. Operators of large facilities should investigate the use of motion detectors if retrofit costs are too expensive for contact sensors.
5. All entry points to the facility should be controlled. In the design of TMCs, the total number of entry points should be kept to a minimum. Personnel entering the facility should use a unique access code/card and/or biometric signature to gain access. Visitors to the center should be logged and escorted at all times. CCTV should be placed at all entry points to the facility.

Third-Tier Defenses (Internal Security)

1. Internal access should be controlled. Personnel should only be given access to what is required to do their job, and their access should be granted by with the same access code/card and/or biometric signature. This type of access restriction is also referred to as “zoned access.” Operators at larger facilities, especially if the building is shared with other tenants, should monitor access to stairwells and elevators.
2. Operators at larger facilities, especially if the building is shared with other tenants, should use internal cameras to monitor all major facility corridors, stairwells and control rooms.
3. All essential control and equipment rooms should have access monitored in both directions using access card readers. Both this information and video footage should be logged for at least three days for security purposes.
4. Management should investigate the advantages of either having local law enforcement liaisons on-site or at co-locating with law enforcement. Local law enforcement offers another level of external and internal security, as well as, improved TMC efficiency for the coordination of emergency response.
5. Internal windows should only be designed to open if they are used for emergency exits and/or essential access points to facility operations.
6. All internal windows and doors should be fitted with sensors to monitor access. This will be easiest for new construction and smaller facilities. Operators of large facilities should investigate the use of motion detectors if retrofit costs are too expensive for contact sensors.

Fourth-Tier Defenses (System Redundancy and Protection)

1. The TMC should have system redundancy. There should be power and operational redundancy within the TMC. For large TMCs, the secondary system should be able to handle all major TMC operational systems and life-support (e.g. lighting, HVAC, drinking water supply) for at least the amount of time of the longest regional disaster that affected any of the systems covered by the secondary system. Also, some or all of the systems capabilities should be able to be remotely operated through TMC, another fixed location substation, or a mobile command center. It may be

more cost-effective for operators of smaller TMCs to investigate coordinating remote operations through larger TMCs.

2. Computer and communication systems should be monitored for illegal access and protected from illegal access with firewalls and other software. All equipment that could impact the safety of motorists along the roadways monitored by the TMC should have default overrides that do not allow for improper use, such as the default setting in signal controllers that will not allow for all-green for opposing lanes of traffic.
3. All system redundancies should be password protected to avoid illegal overrides of system operations.

DISCUSSION

The general finding of the author was that TMCs in the United States appear to have adequate security precautions against hard-attacks based on current expected threat levels; however, most of the facility operators should upgrade their building security. It is the belief of the author that all entrances and exits to the facility be monitored closed-circuit television (CCTV) and/or passive sensors (see Figure 7). Internal security should be controlled and monitored using zoned door-access cards (personnel are only given access to certain portions of the facility), passive sensors on all internal points of entry, and CCTV (only used in key areas such as the operation control center). Also, all of the essential systems (e.g. equipment vital to incident and emergency management response) of a TMC should have redundancy designed into them. The redundancy should include secondary systems to backup the primary systems, but it should also include remote operability by at least one other TMC facility.

Furthermore, these systems should be protected from physical and electronic intrusion. The physical protection of the systems inside a TMC is governed by the first three tiers discussed in the report, but many facilities have other remote operation sites for individual components or portions of the systems operated remotely by TMCs that are not covered by the first three tiers. Hence, electronic monitoring of the system can help extend security to the remote locations in the field away from the TMC. The system monitoring should also include password protection, encryption and firewalls, because the more redundancy that is added to a system, the more susceptible a system is to intrusion.

The author believes that the following areas require additional research:

- Investigate TMC facility access;
- Investigate the reinforcement of the external windows to meet the appropriate perceived threat level;
- Investigate the security concerns in the event of power loss and/or fire;
- Investigate the vulnerability of the operation and communication systems to computer hacking and other forms of sabotage and infiltration (e.g. electro-magnetic pulse could destroy the entire system);
- Investigate the vulnerability of video surveillance and access cards to computer hacking and other forms of sabotage and infiltration;

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- Nora Miles Texas A&M University System

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APPENDIX A: BLANK SURVEYS

TMC Security Survey

TOPIC: Assessment of the Physical Security at TMCs

The purpose of this survey is to establish the current state-of-practice with regard to the physical defense of Transportation/Traffic Management Centers (TMCs) in the United States. The responses to the survey will be separated from the respondents and their respective facilities for the sake of internal security and they will be used to establish recommendations as to basic needs of all TMCs for their physical defense against destruction and/or capture.

Please, feel free to either make responses directly to this form in Microsoft Word, or to print this form out with either extra space for your answers or use additional sheets of paper to complete your responses. **All responses should be mailed, e-mailed, faxed or phoned to Jeff Miles by June 30, 2003.** There may be need for clarification with regard to your responses, please provide the best and the preferred means to contact you. Any questions with regard to this survey can be directed to Jeff Miles.

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Disclaimer: All responses will be separated from there source to ensure the anonymity of the respondent for the protection of their respective facility. If you, the respondent, are uncomfortable with responding via the internet to this survey, you may contact the administrator of this survey directly by phone or written submittal with your answers. His contact information is at the bottom of this Survey. Please, answer each question in the amount of detail in which you are both comfortable and knowledgeable.

1. Are there any physical structures (e.g., gated fence, bollards) and/or added security (e.g., cameras, guards, motion sensors) that separate the grounds on which your facility was erected with your surroundings? If yes, please, explain. In the final report this will be considered a first tier defense.
2. Are there any physical structures (e.g., gated fence, bollards, and security guards) that separate the facility from the grounds on which your building is erected? If yes, please, explain. In the final report this will be considered a first tier defense.
3. Is there any building security (e.g., cameras, guards, motion sensors, standard or electric door locks, bullet proof and/or reinforced windows, windows only on second floor or above) that separates the facility from immediate grounds surrounding the building. If yes, please, explain. In the final report this will be considered a second tier defense.
4. Is your facility contained within a stand alone building or is your facility shared with other organizations/agencies? If your facility is shared by other entities, please, describe to the extent at which you are separated from the other organizations (e.g., concrete walls, simple partitions, no separation), and provide the names and/or general purpose of the other entities (e.g., local police, fire, EMS, private contractor).
5. Does your facility contain any internal security (e.g., cameras, motion detectors, key card access, security contingent, bullet proof windows)? If yes, please, explain. In the final report this will be considered a third tier defense.
6. What are the roles of your facility? Please, include any joint roles, such as disaster response monitoring and remote operation and civil defense monitoring.
7. What is the hierarchal structure of your facilities command structure and who operates your facility? In other words, who do you report to in regular operations and emergency operations and do transportation (public and/or private) engineers primarily operate the facility or does some form of law enforcement or other entity operate the facility? Please, explain.
8. Does your system have redundancy? If yes, please, explain to what extent (e.g., can another facility take control of your normal operations in the case of emergency)? In the final report this will be considered a fourth tier defense.
9. Please, summarize any other general comments that may have not been addressed in the questions and provide any questions that you may be concerned about with regard to the protection of our nation's TMCs.

Thank you for your time and information. Your input will be very valuable to this research.

TMC Security Recommendations Survey

TOPIC: Assessment of the Physical Security at TMCs

The purpose of this survey is to seek comments back from Transportation/Traffic Management Centers (TMCs) that had submitted responses in the preliminary TMC security state-of-practice survey with regard to the recommendations for the minimum security that should be implemented at all TMCs. The responses to the survey will be separated from the respondents and their respective facilities for the sake

of security and they will be used to revise recommendations as to basic needs of all TMCs for their physical defense against destruction and/or capture.

Please, feel free to either make responses directly to this form in Microsoft Word, or to print this form out with either extra space for your answers or use additional sheets of paper to complete your responses. **All responses should be mailed, e-mailed, faxed or phoned to Jeff Miles by July 16, 2003.** There may be need for clarification with regard to your responses, please provide the best and the preferred means to contact you. Any questions with regard to this survey can be directed to Jeff Miles.

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Disclaimer: All responses will be separated from there source to ensure the anonymity of the respondent for the protection of their respective facility. If you, the respondent, are uncomfortable with responding via the internet to this survey, you may contact the administrator of this survey directly by phone or written submittal with your answers. His contact information is at the bottom of this Survey. Please, answer each question in the amount of detail in which you are both comfortable and knowledgeable.

After careful assessment of responses from the preliminary TMC security survey, the recommendations below are suggested for implementation at all TMCs to ensure that the minimum necessary security levels are established to protect the operators of TMCs and their respective city infrastructure. Please, rank each recommendation from your point-of-view and how your respective TMC rates against each recommendation using the following criteria:

- Please, indicate whether you agree (A), partially agree (P) or disagree (D) with each recommendation according to your experience and point-of-view. Please, express any reasons as to why you disagree with a recommendation or what you may disagree with in particular.
- Please, indicate whether your TMC ranks as a “1”, “2”, or “3” with respect to the level you believe your TMC is succeeding for that particular recommendation (1 is the lowest and 3 is the highest). If you agree of the recommendation, but you rank your TMC low, explain why and if you are in the process of making changes.

Defense Tier	Recommendation	A/P/D	1/2/3
1	The perimeter of the TMC should be fenced on at least three sides with a non-flammable material (e.g. wrought iron or masonry). All perimeter lines that are not fenced and/or have long tangents perpendicular to the facility perimeter (long tangents would allow for ramming velocities) should have bollards or other crash abatement devices installed along these key locations that might permit a perimeter breach by a vehicle.		
2	The facility exterior structure should comprise primarily of reinforced, non-flammable material (e.g. masonry).		
	Minimal glass should be used on the exterior of the TMC and all glass used on the exterior should be at least reinforced to handle the most adverse weather conditions of the region (e.g. tornados, hurricanes, etc.). If possible, glass should only be used on the second floor of the exterior or higher. If glass is used on the first floor, it should be used for internally lighting conditions, and it should be narrow (as to not allow as an alternate entry point) and placed as high as possible on the exterior wall. This is a second tier defense parameter.		
	All entry points to the facility should be controlled. In the design of TMCs, the total number of entry points should be kept to a minimum. Personnel entering the facility should use a unique access code/card and/or biometric signature to gain access. Visitors to the center should be logged and escorted at all times. Cameras should be placed at all entry points to the facility. This is a second tier defense parameter.		
	All external windows should be permanently fixed (can not be opened).		
3	Internal access should be controlled. Personnel should only be given access to what is required to do their job, and their access should be granted by with the same access code/card and/or biometric signature. Access to stairwells and elevators should also be controlled in this manner. This is a third tier defense parameter.		
	Internal cameras should monitor all major facility corridors, stairwells and control rooms. This is a third tier defense parameter.		
	All internal windows should be permanently fixed (can not be opened).		
	The facility should be shared with local law enforcement with jurisdiction along the roadways monitored by the TMC. Local law enforcement offers another level of external and internal security, as well as, improved TMC efficiency for the coordination of emergency response.		
4	The TMC should have system redundancy. There should be power and operational redundancy within the TMC. The secondary system should be able to handle all major TMC operational systems and life-support (e.g. lighting, HVAC, drinking water supply) for at least the amount of time of the longest regional disaster that affected any of the systems covered by the secondary system. Also, some or all of the systems capabilities should be able to be remotely operated by another TMC, another fixed location substation, or a mobile command center.		
	Computer and communication systems should be monitored for illegal access and protected from illegal access with firewalls and other software. All equipment that could impact the safety of motorists along the roadways monitored by the TMC should have default overrides that do not allow for improper use, such as the default setting in signal controllers that will not allow for all-green for opposing lanes of traffic.		
	All system redundancies should be password protected to avoid illegal overrides of system operations.		

Please, provide any additional comments as to your assessment of the above recommendations.

Thank you for your time and information. Your input will be very valuable to this research.

APPENDIX B: SURVEY SUMMARY TABLES

Physical Defense Summary Table

Total Number of Respondents (survey 1): 19

Total Number of Respondents (survey 2): 11

Defense Tier	Attribute	Total	Portion	TMC																		
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	<i>Perimeter Security</i>																					
	No Fence	6	32%		X								X	X				X	X	X		
	Fence (open), 3 sides	8	42%				X	X	X	X	X	X					X					X
	Fence (closed)	5	26%	X		X									X	X					X	
	Gate Guard	8	42%			X	X	X	X	X	X	X					X					
	Locked Gate, Unique Code	5	26%	X		X									X	X					X	
	Bollards/Crash Abatement Treatments	3	16%			X							X								X	
	Guard Patrols	7	37%			X	X	X	X	X			X				X					
	Cameras	2	11%													X	X					
2	<i>Building Security</i>																					
	Controlled Entry	18	95%	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	Single Entry Point	1	5%														X					
	Door Locks (individual unique code)	18	95%	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	Reinforced Windows	2	11%	X											X							
	Bulletproof Windows	0	0%																			
	Non-Flammable Walls	2	11%	X													X					
	Guards at Entry Points	5	26%	X		X							X			X	X					
	Guard Patrols	2	11%										X				X					
	Cameras	8	42%	X	X	X							X		X		X			X	X	
	Intrusion sensors (on glass and doors)	1	5%																		X	
3	<i>Internal Security</i>																					
	Stand-alone facility	3	16%			X															X	X
	Shared Facility w/o restrictive barriers	9	47%			X					X	X			X	X			X	X	X	X
	Shared Facility w/ restrictive barriers	10	53%	X	X		X	X	X	X			X	X			X	X				
	Shared with Law Enforcement	7	37%		X	X								X	X	X	X			X		
	Controlled Entry	18	95%	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	Door Locks (standard)	1	5%																			X
	Door Locks (individual unique code)	18	95%	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	Guard Patrols	7	37%			X	X	X	X	X			X				X					
	Cameras	14	74%			X	X	X	X	X	X	X	X	X			X	X	X	X	X	
	Motion sensors	1	5%																		X	
4	<i>Electronic Security</i>																					
	Power Redundancy	10	53%	X	X	X	X	X	X				X			X	X	X				
	System redundancy	10	53%	X		X	X	X	X				X	X			X			X	X	
	Firewall to hacking	1	5%	X																		
	System monitoring	0	0%																			
	Secured links	1	5%										X									
Purpose	Remote Sensing	18	95%	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
	Incident Detection and Management	12	63%	X	X	X							X	X	X	X	X	X		X	X	X
	Travel Information	14	74%	X	X	X	X	X	X	X	X	X	X	X		X	X					X
	Traffic Management	16	84%	X		X	X	X	X	X	X	X	X	X		X	X	X		X	X	X
	Emergency Management	14	74%	X		X	X	X	X	X	X	X	X			X	X	X	X		X	

Physical Defense Summary Table

Total Number of Respondents (survey 1): 19

Total Number of Respondents (survey 2): 11

Defense Tier	Attribute	Total	Portion	TMC*																			
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Survey 1	1	14	74%	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N	N	N	Y	Y	
	2	10	53%	N	Y	N	Y	Y	Y	Y	Y	Y	N	Y	N	Y	N	N	N	N	N	N	
	3	14	74%	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	N	
	4	0	0%	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	
	5	17	89%	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	
	6	0	0%	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
	7	0	0%	**	N	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	
	8	16	84%	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	N	Y	Y	N	
	9	0	0%	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
Survey 2	1 (A,P,D)	4	36%	P	A	A	D	P	P	A	P	P	P	A									
	1 (1,2,3)	3	27%	3	3		1	2	1	1	2	1	2	3									
	2 (A,P,D)	7	64%	A	P	A	A	P	P	A	A	P	A	A									
	2 (1,2,3)	4	36%	2	2		3	3	1	2	3	2	2	3									
	3 (A,P,D)	8	73%	A	P	A	P	A	A	A	A	A	P	A									
	3 (1,2,3)	3	27%	2	2		3	3	2	1	2	1	2	3									
	4 (A,P,D)	10	91%	A	A	A	A	A	A	A	A	A	P	A									
	4 (1,2,3)	5	45%	3	3		3	2	1	2	3	3	2	1									
	5 (A,P,D)	8	73%	A	A	D	A	P	P	A	A	A	A	A									
	5 (1,2,3)	8	73%	3	3		3	3	1	3	3	3	2	3									
	6 (A,P,D)	9	82%	A	P	A	A	A	A	A	A	A	D	A									
	6 (1,2,3)	3	27%	3	2		3	2	1	2	3	2	2	1									
	7 (A,P,D)	2	18%	A	P	P	P	P	P	A	P	P	D	P									
	7 (1,2,3)	2	18%	2	3		1	1	1	3	2	1	2	1									
	8 (A,P,D)	7	64%	A	P	D	A	P	P	A	A	A	A	A									
	8 (1,2,3)	9	82%	3	3		3	3	3	3	3	3	2	3									
	9 (A,P,D)	8	73%	A	D	P	A	A	A	A	A	A	A	P									
	9 (1,2,3)	3	27%	3	1		3	1	1	1	3	2	2	1									
	10 (A,P,D)	11	100%	A	A	A	A	A	A	A	A	A	A	A									
	10 (1,2,3)	3	27%	2	2		3	2	2	1	3	3	2	2									
	11 (A,P,D)	11	100%	A	A	A	A	A	A	A	A	A	A	A									
	11 (1,2,3)	6	55%	3	3		3	2	1	2	3	3	2	3									
	12 (A,P,D)	9	82%	A	P	A	P	A	A	A	A	A	A	A									
	12 (1,2,3)	5	45%	3	2		2	2	1	3	3	3	2	3									

*Indicates that the TMC reference for the recommendation responses do not necessarily match the responses with the first survey responses.

**The statement was a general answer that did not fit a yes or no response.

JEFFREY DAVID MILES

Jeffrey David Miles is currently pursuing his Master's of Science degree in Civil Engineering at Texas A&M University. He will complete his M.S. in May 2004. While attending graduate school, he is a Graduate Assistant Researcher at the Texas Transportation Institute (TTI). Mr. Miles is investigating rumble strips as a perspective countermeasure to reduce crashes by generating tactile and audio sensations for inattentive motorists. In particular, he is planning on researching centerline rumble strips (CRS) for his thesis.



Mr. Miles has had a diverse academic and professional career. He graduated Advanced with Honors from Richardson High School in 1994. While he maintained an exemplary scholastic record, he also took part as a member and as a leader in numerous organizations and worked through high school as a mentor, a clerk and a food service attendant. He joined the United States Armed Forces and served 4 years in the U.S. Navy. Three-and-a-half years of his service career were spent aboard the U.S.S. Alaska (SSBN 732B). His desire to excel and to serve his nation helped him continue his success through two command advancements, a Navy Achievement Medal and a Junior Sailor of the Quarter.

Upon the completion of his military commitment, he proceeded to re-enter the scholastic arena. In July 1998, He returned home to Dallas, Texas to attend Richland College. While attending Richland College he worked for the U.S. Attorneys' Office for the Northern District of Texas. As a student, he worked hard to maintain a 3.89 GPA with a 17-hour course load per semester while working approximately 20 hours a week. During his studies at Richland College, he was inducted into Phi Theta Kappa and served as the Interim Student Chapter President. After completing thirty-seven academic hours at Richland College, he left to seek his B.S. in Civil Engineering at Texas A&M University.

He has continued to succeed scholastically and professionally at Texas A&M. As a student, he has become an active member of the American Society of Civil Engineers (ASCE), the Institute of Transportation Engineers (ITE) and the International Golden Key Honor Society. He served one semester as Vice-President for the Texas A&M ITE Student Chapter, before being elected to his current position as President of the Student Chapter for the year 2003.

Three of his proudest moments in past 5 years can be directly attributed to Texas A&M University. His first moment occurred when he was selected to represent the University in the 2000 Ethics Bowl in Washington, D.C. as part of its ethics team. Then, he was accepted to partake in the Undergraduate Fellows Program for the summer of 2002. The research experience that he gained was incalculable, and it has aided him in Graduate School. With regard to Graduate School, his most recent honor was receiving his Graduate School acceptance letter.

His professional growth has come through his exposure to professionals in ITE and through his work at TTI. Mr. Miles has worked for TTI since February 2001.

Another blessing that is completely unrelated to his academic and professional career is that he married Nora Hogue in June 2001. He has worked hard to continue to learn about budgeting his time between his family, school, work, and other activities to maintain his 3.56 GPA.

It is his desire to study transportation engineering and to direct his energies towards research in the areas of intelligent transportation systems (ITS), access management, signage, and geometric and safety design during his graduate studies and throughout his remaining career.

A NEW REVENUE GENERATING METHOD FOR TRANSPORTATION FUNDING: THE VEHICLE MILES TRAVELED FEE

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SUMMARY

Today fuel taxes comprise 60 percent to 70 percent of highway funds for states, but the future of the fuel taxes faces serious issues. Vehicles today are more fuel-efficient than twenty years ago, and the fuel tax has not been raised recently to keep pace with inflation and rising construction costs. Alternative fuels have further reduced the buying power of the fuel tax. Because of these trends there is a renewed interest on different ways to finance transportation in the United States. One method recently being explored is the vehicle miles traveled (VMT) fee. The VMT fee assesses a specified fee for each mile driven to road users.

A literature review and interviews with professionals were conducted to explore the many methods that a VMT fee could be implemented. From these sources benefits of the VMT fee over the current fuel tax were identified. The barriers that would prevent the VMT fee from being implemented were determined by the author, along with techniques to overcome these barriers. Finally, steps for an implementation process of the VMT fee were created for a state government to follow.

The barriers identified in the VMT fee implementation process are classified into four general categories. The categories are:

- Public perception;
- Technological;
- Political; and
- The implementation process.

The current feasibility of the VMT fee depends on the method chosen and purpose of collection. The only method that could be implemented today is an odometer reading method. An odometer reading VMT fee would be sufficient to supplement, but not replace, the current fuel tax. A more comprehensive system, like the GPS/GIS method of collection, would be needed to completely replace the fuel tax.

The implementation of a VMT fee user system will take the coordinated efforts of many state government agencies. Most likely the implementation process will span 20 years or more, from the time the VMT fee is considered to when the current fuel tax collection system is completely phased out. It is important to begin exploring the possibilities of the VMT fee early because it will take 10 years to have an operational user fee system. The follow steps are an implementation plan for the VMT fee that could be employed by a state government:

1. Create a task force;
2. Small scale pilot tests;
3. Devise/propose legislation;
4. Physical/institutional infrastructure installation;
5. Start-up with concurrent VMT fee and fuel tax; and
6. Full implementation.

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INTRODUCTION

Since the beginning of major public highway construction, fuel taxes have been the primary revenue generator for transportation projects. In most states today, fuel taxes comprise 60 percent to 70 percent of the total transportation fund. However, the fuel tax in most states has not increased much since the 1980s due to political and public opposition.

Nevertheless transportation project costs continue to rise. The American Association of State Highway and Transportation Officials (AASHTO) recently released a report with figures on expected transportation spending over the next twenty years. In the report it states that in the United States, \$75.9 billion dollars will need to be spent annually over the next twenty years to maintain the current highway system in place. It will cost \$106.9 billion dollars annually to maintain and improve the highway system to meet growth (1). Current levels of federal spending on transportation during TEA-21 are roughly \$34 billion dollars annually, leaving states and local governments to cover the remainder of the necessary expenses.

Another significant problem facing the transportation industry is the fact that the money generated per vehicle-mile from the fuel tax is decreasing. This decrease comes from the fact that vehicles today are more fuel efficient than in the past. Vehicles in 2000 averaged 19.6 miles per gallon compared with the fuel efficiency of 14.4 miles per gallon in 1980 (2). While fuel tax revenue has increased over the past twenty years because people are driving more, it has not kept pace with the growth of vehicles on the road today. With the recent release of hybrid vehicles that have a fuel efficiency of between 45 and 50 miles per gallon, the average fuel efficiency will continue to increase. Also, many vehicles today are using alternative fuels, which are fully or partially exempt from the fuel tax, decreasing revenue further. When hydrogen powered vehicles are released into the market, they will not even need to fuel with gasoline. The future buying power of the fuel tax will continue to decrease.

A new approach could be implemented, in order to generate the necessary revenue. Instead of charging on the basis of gallons of gasoline consumed, a user-based fee would charge vehicle owners on the amount of miles driven. The vehicle miles traveled (VMT) fee would be assessed to all vehicles, regardless of fuel-type.

Currently no state assesses a VMT for all vehicles. Oregon assesses a weight-distance fee for commercial vehicles operating within state boundaries. Governments are beginning to consider the VMT fee as an option to supplement fuel tax revenues and recognize the potential of these fees to replace the fuel tax in the future (3). Applications of the VMT fee range in technological advances from a simple odometer reading at the time of vehicle registration to equipping each vehicle with an on-board computer and global positioning system (GPS) to measure the distance traveled by a vehicle.

RESEARCH OBJECTIVES

The purpose of the proposed research is to identify the current research and technology applications being performed relating to the VMT fee from a literature review and contacting qualified experts. This research will then address the issues that confront the VMT fee and possible implementation. The major objectives of this research paper are:

- Perform a literature review on VMT fee research.
- Identify the different methods of applying the VMT fee.
- Identify the issues facing the implementation of the VMT fee.
- Provide an implementation plan of the VMT fee at the state level of government.

SCOPE

The scope of this research includes a review of the current studies involving VMT fees and technology that could be applied to a VMT fee system in the United States. The research paper will include current GPS technology that could be implemented in a VMT fee pricing system. VMT fee research and implementation outside the United States (if any) will be noted, but not researched in depth. Contacts will include member of automobile corporations, state departments of transportation (DOT), and professional researchers. VMT fee application will be considered on the local, state, and national level, but implementation processes will focus on the state level of government.

STUDY DESIGN

Four procedures were followed while conducting this research project with the purpose of developing an implementation plan for the VMT fee at the state level of government. Each procedure is described in this section.

Literature Review

Past and current research on the topics of fuel tax revenue and VMT fees was reviewed to provide a basic understanding of the subject. State governments and transportation research organizations have conducted research into the VMT fee. The literature was collected from an extensive Internet search and from receiving documents from groups conducting current research.

Develop and Conduct Interviews with Professionals

Research professionals and members of state DOTs were identified in the literature review and through personal contacts. After developing a set of interview questions, each member identified was contacted by e-mail and invited to participate in an interview. The interview process was an important information gathering procedure because of the newness and the broad application of the VMT fee. The interview questions can be found in Appendix A.

Identify Benefits and Barriers of the VMT Fee System

In order to predict the success of a new revenue system both benefits and barriers were identified. In addition to identifying the major barriers, solutions to these barriers were explored. It was found that these solutions are vital in developing the implementation process.

Develop an Implementation Plan

An implementation plan for the VMT fee was developed for the state level of government. The objective of this plan was to include:

- The proposed method of applying the VMT fee along with the physical infrastructure needed;
- Key departments in the state government that would be included in the implementation process;
- Time frame of implementation; and
- Procedures to overcome the major barriers associated with the VMT fee.

BACKGROUND

The largest revenue generator for transportation projects is the fuel tax. It comprises between 60 percent and 70 percent of the total transportation revenue for states. The first fuel tax was imposed by the state of

Oregon in 1919 at the rate of one cent per gallon of gasoline sold (2). Soon after other states followed suit, and in the 1930s, a national gas tax was instituted. Up until the 1980s, fuel tax rates were increased periodically to keep pace with inflation and highway construction. Since the early 1990s, most state fuel taxes have not been increased because of public and political opposition. Much of the general public believes that because the freeway system is completed, transportation related funding does not need to continue to rise. This is not the case, however.

State fuel taxes range from 7.5 cents per gallon (Georgia) to 29 cents per gallon (Rhode Island) (4). The majority of state fuel taxes range between 15 cents per gallon and 20 cents per gallon. The federal tax rate on gasoline is currently 18.4 cents per gallon. The national fuel tax is distributed among the states based on the percentage of tax revenue collected from each state, and the need of certain federally funded transportation projects. The average driver pays about \$150 per year in fuel taxes.

The revenue from the fuel tax is decreasing in its buying power. Since fuel taxes have not been significantly raised in a decade, fuel taxes are not keeping pace with inflation, cutting their real buying power. In addition, transportation construction costs continue to rise, making annual state transportation expenditures increase, as revenue from the fuel tax remains level. Revenue from the fuel tax has increased over the last decade because of an increase in travel. This increase is not predicted to continue at the same rate. In addition, the fuel efficiency of the average vehicle will continue to increase due to better technology for gasoline engines, more hybrid vehicles in the motor vehicle fleet and the possible introduction of vehicles powered by fuel cells.

In a financial study performed by the Oregon DOT, Oregon predicts that in 2012, state fuel tax revenue will level off and then start to permanently decline over the next decade (2). New approaches for generating revenue to supplement the fuel tax need to be considered before the revenue stream from fuel taxes starts to decrease. A method that places the burden of cost on the road user (direct fee) would be preferential. One method being researched currently is the VMT fee.

VEHICLE MILES TRAVELED (VMT) FEE APPLICATION

Because the VMT fee is a completely new form of assessing a road fee, a new institutional system would have to be developed to implement it. Road users would be assessed a specified fee for each mile driven under the VMT fee. Unlike the current fuel tax, the VMT fee has the attractive feature of generating revenue that is unaffected by the amount or type of fuel that is consumed by a vehicle (5). VMT fees are based on road use, not fuel consumed. VMT fees can be assessed equally to traditional gasoline powered vehicles, hybrid vehicles, hydrogen fuel celled vehicles and any other type of vehicle that will be produced in the future.

The rate at which the VMT fee is assessed can vary among vehicle classes. These rates are based on the amount of damage to the roadway and environment each vehicle class causes. Heavier commercial trucks will pay more than an average passenger vehicle because commercial trucks produce more damage to the pavement and roadbed materials. Also, emission production rates could be taken into account in the VMT pricing scheme. Higher polluting vehicles could be assessed a higher fee. Federal researchers have determined that VMT fees based on the cost that users impose on the roadway is the fairest and most efficient form of assessing a travel fee (6).

By charging a fee directly on road use, policy makers will be able to determine the price the public is willing to pay for transportation improvements and maintenance (7). Unlike the current taxing system where the tax is hidden in the price of gasoline, road users will be aware of how much they are paying because the VMT fee can be calculated straight from miles traveled. This makes the cost more “visible” to the road user. Drivers will know they will be taxed a certain amount for traveling a certain distance. With the current fuel tax, road users are being charged indirectly for their road use. Vehicle owners are

indirectly paying a tax on distance driven, but the tax is based on the amount of fuel consumed so it is not as apparent to the driver the amount of tax being charged.

Researchers predict that people's travel patterns will change depending on the rate per mile charged. Both the California Environmental Protection Agency and the Victoria Transport Policy Institute (VTPI) estimate that a VMT fee of additional 2 cents per mile would reduce the total vehicle miles traveled in the country by 4 percent (8,9). While possibly not appearing to be significant, this reduction in travel would lessen congestion. The VTPI estimates that an additional 1-cent per mile charge would reduce vehicle miles traveled by 1.5 percent.

It was determined that a rate of 1.25 cents per mile driven would be an acceptable price for the VMT fee in a recent research report written by the state of Oregon (10). This rate would be sufficient to completely replace the current fuel tax system and provide Oregon with sufficient funds to cover transportation expenditures. The average vehicle owner would spend between \$150 and \$200 annually on the VMT tax, which is currently what the average driver spends on fuel tax each year.

The primary objective of the VMT fee is to provide a fair, stable source of user-generated revenue to support the transportation system. The fee revenues should be returned to the jurisdiction where travel occurred. To achieve this objective, researchers from the Public Policy Center at the University of Iowa identified seven characteristics that a VMT fee system should possess to be successful (3). The characteristics are:

- User Friendly
- Preserve User Privacy
- Convenient
- Secure
- Robust
- Reliable
- Flexible

The first three of these characteristics address the relationship of the system and the general user, while the final four attributes deal with the goals of the public agency in charge of administering the VMT fee.

Methods for the Application of the VMT Fee

Different approaches on how the VMT fee could be applied are being studied and considered. Each approach has specific benefits and drawbacks, and ranges in technological feasibility. The most common VMT fee methods being considered from simplest to most technologically advanced are:

- Odometer/Hubodometer Reading;
- Gas Efficiency Index Charge;
- Automatic Vehicle Identification (AVI) Technology; and
- GPS/GIS System.

Each of these methods will be described briefly, with the main focus of this paper concentrating on the GPS/GIS system.

Odometer/Hubodometer Reading

The simplest approach toward implementing a VMT fee would be to read the odometer of each registered vehicle periodically and assess a mileage fee on that reading (Figure 1). Implementing such a system would be relatively easy because no new technology would have to be applied. Official odometer reading

stations could be established where each vehicle would be required to visit annually to be inspected. This reading could be done in conjunction with state emissions inspections, state safety inspections, or any other state vehicle inspection program.

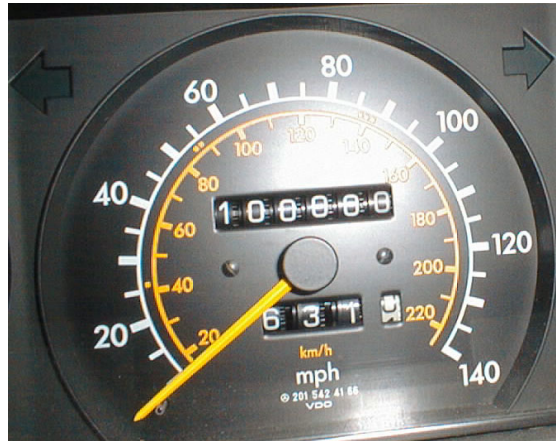


Figure 1. Odometer Reading

Before the time the vehicle registration is due, the owner of the vehicle would report the amount of mileage driven since the previous odometer inspection, and a VMT fee would be assessed to the vehicle registration. The steps involved in the VMT inspection would include:

1. Check the speedometer/odometer unit for indications of tampering (such as signs that the speedometer unit has been removed, or marks on the counter itself).
2. Attach a small seal to the ends of mechanical odometer cables to indicate if the cable has been disconnected. This is only necessary in older vehicles that do not have electronic speedometers that are integrated with the engine computer.
3. Check tires for the correct size.
4. If a dynamometer is available, speedometer and odometer accuracy checks can be performed (optional).
5. Record the odometer reading and transmit the results to the institution that will bill the VMT fee to the vehicle owner. This data transfer should be done electronically.

Performing this odometer reading would take five to ten minutes (*11*). Assuming this VMT reading occurs with other state inspection plans, the cost increase, including labor, to perform the odometer reading is estimated at \$10 per vehicle.

One major flaw with the odometer reading method would be the ability for vehicle users to evade full payment by tampering with the odometer. This method of the VMT fee is predicted to have higher evasion rates than the current fuel tax system (*5*). With new technologies, odometer tampering can be more readily detected and stopped. The VTPI argues that odometer tampering and tax evasion should be minimal for the following reasons:

- New vehicles have increasingly tamper resistant odometers. Most new vehicles possess a digital odometer that is difficult to reset because mileage data are recorded in the engine computer.
- Odometer tampering would save only between \$500 and \$1,000 over the lifetime of the vehicle. The cost associated with tampering could be this much.
- Private vehicle owners do not have access to professional odometer rollback experts. Amateurs often leave signs of tampering (*11*).

In addition, government policies, such as placing large fines on vehicles with tampered odometers could prevent VMT fee evasion. If fines were greater than \$500, the reward for evasion would not outweigh the risk of detection.

The administration of an odometer audit-based VMT fee would be similar to the vehicle licensing and registration institutions in place today. Besides creating the rates structure and training technicians to perform the odometer readings, no new institutions would need to be developed with this simplistic form of VMT fee application.

In place of an odometer, a hubodometer could be placed on the vehicle to measure vehicle miles traveled. A hubodometer is mounted on the axle hub of the vehicle (Figure 2), and it measures the distance traveled. Many fleet vehicles currently use hubodometers to facilitate scheduling and maintenance. Hubodometers are more secure from tampering than regular odometers because they come factory-sealed. Each new vehicle could be required to have a hubodometer on board, and this would be used in the annual mileage reading instead of the odometer. One advantage in using hubodometers over each vehicle's odometer is that the agency involved in VMT reading could standardize the equipment used in the VMT audit. Prices for simple, mechanical hubodometers range from \$25-\$50 for the hubodometer and installation (*12*).



Figure 2. Hubodometer

Gas Efficiency Index Charge

Another method for implementing the VMT fee would be to equip vehicles with a device attached to the gas tank entrance that identifies vehicle type and its average miles per gallon fuel consumption. This device would interface with the gas nozzle when refueling. Each time the vehicle is refueled, the device would be read at the gas pump and the driver would be assessed a miles traveled fee by how much gasoline was pumped. The VMT fee would be added to the fuel charge at the pump and then distributed to the government by the gas retailer. The privacy of a driver would be protected because no unique identity number would be needed on a vehicle (*5*).

Because the gas efficiency index charge is so similar to the current fuel tax, it would not be worthwhile to change systems. The same problems exist with this method, as the current fuel tax. A gas efficiency index approach only takes into account petroleum fueled vehicles. Also, the devices that identify vehicles would have to be installed on all vehicles and all gas pumps would have to be retrofitted to be able to read such a device. These devices would cost billions of dollars for a state government to install and take years to accomplish.

Automatic Vehicle Identification (AVI) Technology

Automatic vehicle identification technology is used extensively on toll roads. Roadside “readers” are placed intermittently to scan vehicles passing by and identify them. To make this possible each vehicle has some form of radio frequency or infrared device (toll-tag) on-board to identify itself to the “reader.” Toll facilities use this technology to identify vehicles entering the toll facility, passing through a tollgate, and exiting the toll facility. The information is then collected and proper fees are assessed to the vehicle’s owners and a fee is charged to their account.

AVI technology is currently used on urban highways to monitor traffic characteristics. Authorities in urban areas that have toll roads are able to place roadside “readers” at key locations along freeways and determine freeway speeds. Speeds are calculated from the time it takes for one vehicle equipped with a toll-tag to travel between two “readers”. These “readers” that are not on the toll road do not charge tolls, but only collect travel data to help transportation officials.

The AVI technology is very reliable on closed road systems, such as toll roads. However, it would be very difficult to apply AVI technology to a state’s entire roadway network. AVI “readers” only record the passage of a vehicle at a certain point, not the number of miles traveled by the vehicle between readings; it would be economically infeasible to place AVI “readers” on the entire transportation network (12).

GPS/GIS Technology

The final approach for a VMT fee would be to install an on-board computer in each vehicle. Each computer would be equipped with a Global Positioning System (GPS) receiver and a Geographic Information System (GIS) database. Vehicle movement and distance traveled would be recorded in the computer, and the VMT fee for a specified area would be calculated on-board the vehicle. The fee amount would be stored inside the on-board computer until paid. The fee information from the on-board computer could then be uploaded periodically at official upload stations and the motorist could choose a method of payment for the VMT fee. Uploaded information would be sent directly to the central collection agency. An overview of the GIS/GPS collection system is shown in Figure 3.

GPS/GIS VMT COLLECTION SYSTEM

All new vehicles would come equipped with an on-board computer that possesses a GPS receiver. These on-board computers would be able to calculate the vehicle miles traveled and assess the appropriate VMT fee. GPS receivers obtain surface coordinate information from signals emitted by satellites orbiting the earth. In addition to the GPS receiver, the computer would contain a GIS database system and fee schedule for the entire country. This would enable the computer to assess VMT charges anywhere in the nation. The fees assessed in each geographic district could then be charged and collected by that district.

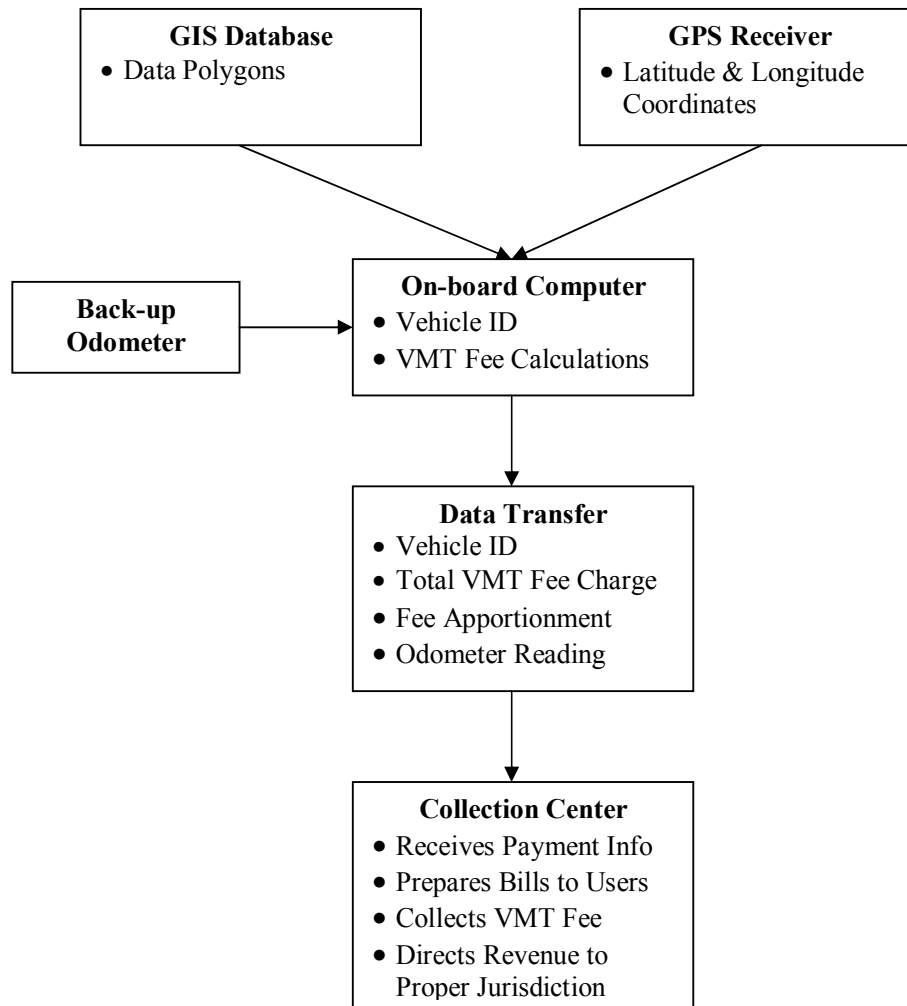


Figure 3. Overview of the GPS/GIS VMT Fee Collection System

A back-up system on the computer would also have to be installed in case of malfunction or tampering with the main GPS system. An electronic hubodometer connected to the on-board computer could be used for the back-up system (3). This odometer would feed travel information to the on-board computer and assess the VMT fee to the home jurisdiction of the vehicle. The back-up system would be activated for two reasons. First, the GPS receiver is not able to pick up a signal from the satellite because of mountains, an urban central business district with large buildings (urban “canyons”), or dense tree cover. Second, if for some reason the GPS on-board the vehicle fails, the back-up system would come on-line and notify the driver to service the vehicle as soon as possible.

For the VMT fee system to be successful, only a minimal amount of personal information is required. This information includes:

1. Pricing data within a state;
2. Vehicle type and weight class; and
3. Person/organization to be billed.

Although the technology that would be applied to the VMT fee is new and rather complex, the overall idea of a VMT fee and the information necessary to make it work is simple.

Pricing Zones

It is recommended from recent research that the same fee rate should be charged on travel within a specified geographic region or polygon. A polygon system would simplify the GIS database needed on the on-board computer. This area could be large to start off with. The recommended region would be a statewide VMT fee that is the same for all miles traveled within each state's boundaries (Figure 4) (*3,10*). Different states could assess different rates for the VMT fee according to each state's needs, much like the varying fuel tax rates today. With relatively large polygon areas, the possibility of a user being charged for the incorrect district would be minimal. With larger polygon areas it will be easier to verify which charging area a vehicle is in when the backup system is in use.



Figure 4. State Polygon Boundaries

Ultimately, many transportation planners may like to charge different rates for each mile traveled on different road classifications. Freeways and roadways designed for high volumes would have lower VMT fee prices, and local streets would have higher prices. Current GPS technology does not allow for this type of accuracy. Current technology does allow for the use of GPS to accurately locate a vehicle within 20 feet of its actual position (*13*). As technology improves, and the VMT system becomes more established, polygons can become more specific (such as central business districts, neighborhoods, etc.). It would then be possible to update the GIS database periodically by downloading new district information to the on-board computer.

Data Upload Process

As mentioned earlier, the VMT fee data stored on the vehicle's on-board computer would need to be periodically uploaded to a central collection center. In order to protect people's privacy, the only information that would be uploaded during this process would be the fee owed to each jurisdiction driven in. The information that would be transferred to the collection center is displayed in Table 1. No information on when the travel occurred or which roads were traveled on would ever leave the on-board computer system. The central collection agency would process the uploaded VMT fee information and a bill would be sent to the vehicle owner. Regulations could be established by each state as to the upload frequency. Either a 30-day or 90-day period seem reasonable, depending on the method of data upload chosen by a state. Owners would receive a monthly or quarterly transportation bill, much like utility bills.

Table 1. Information Transferred in Upload Process

Categories	Data
Vehicle ID	IJGGZ676PD459643
Date Range	10152002,10232002
Odometer	18341.6
Total VMT Fee	\$3.91
Rate Schedule Edition	4.2.02

Upload Technology

Technologies exist today that could be used for uploading the fee information from the on-board computer to the central collection center. These technologies are in use in other sectors, but have not been directly applied to the transportation sector before. The two methods being considered by researchers today are the use of smart card technology and transmitting data to an intermediate hub using radio frequencies. Pilot tests for both technologies are scheduled to begin in 2004 (3).

Smart Card Technology. A smart card resembles a credit card, and has a microchip in the form of a memory module imbedded in it. The smart card is able to interface between the on-board computer and the collection agency. Smart cards are placed in a holder that is connected to the on-board computer (Figure 5). This holder should be placed in an accessible location of the vehicle, so that the smart card can be removed for uploading purposes. VMT fee charges will continuously be downloaded onto the smart card's memory chip. When payment is to be processed the smart card can be removed from its holder and taken to an upload station.

The upload stations resemble ATM machines. These machines would be located in public places, such as grocery stores, convenience stores, malls, banks and/or gas stations. To upload VMT fees, one would insert the smart card in the upload machine, so that the smart card's microchip can transfer data to the upload machine. Charging information would then be sent to the main collection agency. A method of payment could then be selected. Drivers could pay on the spot with a credit card or have a bill sent to them from the central collection center. The central collection agency most likely will be a private firm contracted out by the government. Its main purpose, besides collecting the VMT user fees, would be to distribute the funds received to the proper billing districts.

Over a billion smart cards are in use today, mostly in Europe. Current uses of smart card technology include storing electronic money, storing PIN numbers, and personal identification (3). Smart cards cost roughly five dollars each and can be replaced if damaged or if it malfunctions.

Radio Transmission. Transmitting the VMT fee information via radio transmission is another method that could be used. A radio transmission device connected to the on-board computer would transmit the VMT fee information to an intermediate hub receiver. These intermediate hubs would be placed at fueling stations or at other public locations. Each time the vehicle is fueled, the on-board transmission device would pass on the VMT charges for that particular vehicle through a specific radio frequency set aside for VMT fee collection. The intermediate hub receiver would process the transmission and send the VMT fee bill onto the central collection agency electronically, or charge the user directly at the pump. If the driver was charged at the pump, the fee revenue would be collected from gas stations and sent to the proper state agency (14).



Figure 5. Smart Card with Holder

TELEPHONE INTERVIEW FINDINGS

A telephone interview survey was performed to supplement the findings from the literature review. Of the eight people contacted through an initial e-mail contact, three responded. One respondent was from a research organization, one from the Oregon Department of Transportation, and the last was from the Federal Highways Administration.

The interview consisted of open-ended questions to help the interviewer come to a broader understanding of the VMT fee and the feasibility of such a system. Depending on the experience and knowledge of the respondent, the following VMT fee related topics were covered. They include:

- Is your agency considering the use of the VMT fee as a source of revenue;
- Methods of assessing the VMT fee;
- Benefits of the VMT fee system over current practices;
- Major barriers to the implementation of the VMT fee;
- Time frame of implementation; and
- Process of implementation.

The complete set of interview questions can be found in Appendix A. Because the respondents were from different engineering and planning backgrounds, their perspectives on the VMT fee differed from one another.

General Interview Findings

Presently, Oregon is the only state that is considering legislation to assess a VMT fee on all vehicles. Oregon has established a Road User Fee Task Force (RUFTF) to research all possible VMT fee systems and to evaluate each system. The RUFTF is set to begin a three-year testing program that will investigate the feasibility and reliability of the GPS-based VMT fee. FHWA has not yet identified the VMT fee as an option to finance transportation at the national level. However, FHWA is participating in VMT fee research projects.

The two VMT fee methods that have a possibility of being implemented are the odometer reading method and the more advanced GPS/GIS method. All respondents agree that the GPS/GIS technology needs to

be tested in pilot programs before being implemented. If the odometer reading technique were instituted now, the GPS/GIS method of VMT fee assessment would replace the odometer reading method sometime in the future.

All the respondents mentioned the same two benefits of the VMT fee over the current fuel tax. First, the VMT fee would truly represent the consumption of infrastructure and rates could be set to provide economic equity to all users. Second, VMT fee revenue would not shrink due to higher fuel efficiency.

The beliefs among the respondents concerning the barriers to implementation of the VMT are privacy issues and the political resistance to change the current system. The respondents believed that, though numerous, the barriers to implementation are not insurmountable. The successful completion of pilot tests using GPS/GIS technology should help change common misconceptions held by the public and politicians.

Respondents agreed that the implementation process would entail a long transition period. Oregon is planning on introducing a VMT fee bill to the 2007 legislative session, with a goal of having an operating VMT fee system in place by 2013. The other respondents agreed that the implementation of the VMT fee would take at least ten years. If the odometer reading method were used, the timeframe for implementation would be shorter (*15, 16, 17*).

BENEFITS OF THE VMT FEE

In order to implement a new fee system, the benefits of that new system should be clear and different from the existing system. The major benefits of the VMT fee are displayed in Table 2. If the benefits were no different, it would not be worthwhile to switch systems. The VMT fee collection system has many benefits to it.

Table 2. Benefits of the VMT Fee

Benefits
1. No Shrinkage of Revenue Due to Fuel Efficiency
2. Reflects Real Consumption of Infrastructure
3. Reduced Tax Evasion
4. Local Government VMT Fee
5. VMT Based Insurance Premiums

The most important benefit to the VMT fee collection system is that higher fuel efficiencies or alternative fuels would not affect the amount of revenue generated (*18*). As mentioned previously, real fuel tax revenues shrink as vehicles become more fuel-efficient. VMT revenue is not dependent of fuel consumption. VMT fee revenue is based upon mileage driven, which is considered to be a fairer and stable form of assessment. As travel grows, due to increased annual vehicle miles traveled or population growth, the revenue from the VMT fee will continue to grow no matter what technological advances occur.

Vehicle miles traveled fees represent the real consumption of the transportation system. Fuel taxes attempt to do the same, but do not. Fuel tax costs are “hidden” in the price per gallon of fuel. Drivers are not aware of the cost that an individual trip may impose. VMT fees are much more “visible” to the driver because the VMT fee is based solely on distance driven. A driver can then calculate the cost for a

particular trip easily. The VMT fee system makes it easier to charge vehicle groups the real cost they are incurring while driving. Under the fuel tax, passenger vehicles are paying more than their real costs, while heavy commercial trucks are paying less.

Another benefit to the VMT is the predicted reduction of tax evasion if tamper resistant technology is applied. Reports have shown that evasion rate on diesel fuel taxes is somewhere between 10 percent and 15 percent (3). While there will always be a minimal amount of tax evasion, the VMT fee system provides the technology to catch tax evaders. In addition, it has the capability to charge everyone without having individuals fall through the cracks. Technology will play a major role in this aspect, and must become reliable.

Once legislation is in place and GPS accuracy is higher, local governments could begin charging extra fees for travel within their jurisdiction. These local fees could help support the transportation needs of the specified community if so desired.

Other benefits could be realized outside the financing of highways. Insurance companies would be able to adjust insurance premiums based on the annual vehicle miles traveled. Drivers who drive less than average amounts could have lower insurance premiums, while those who drive more would have to pay for that risk. Better trip generation data could be collected because real trip data could be collected, instead of survey results, if a certain amount of the population was willing to be tracked. Better trip generation data would result in more accurate transportation planning models, which could better allocate highway funds. In addition, if the GPS technology were implemented it would be possible to have emergency location notification transponders on each vehicle.

BARRIERS OF VMT FEE IMPLEMENTATION

As with any new system, there are potential drawbacks to the implementation of the VMT fee collection system. These drawbacks will have to be weighed against the drawbacks of the fuel tax system before any decision is made for implementation. Many of the potential barriers mentioned from research groups can be overcome with successful demonstrations of how the VMT fee is to be implemented. The fuel tax has served its purpose in the United States for over 80 years and has been successful until now. Switching methods will meet resistance from those who do not like change. Proper education and publicity campaigns should be able to dispel much doubt about the effectiveness of the VMT fee. Barriers to VMT fee implementation fall into four general categories. These categories are:

1. Public perception;
2. Technological;
3. Political; and
4. The Implementation Process.

Each one of these groups, along with the specific barriers to implementation will be discussed. A summary of the barriers to implementation are shown in Table 3 along with solutions to and approaches on how to overcome each barrier.

Public Perception

The public must realize why a new method for generating revenue for roadways is necessary. If this reasoning is not clearly presented, there will be opposition to the implementation of the VMT fee. The public will view this method as just another way for the government to assess more taxes. While the actual annual amount of money a user pays will not differ significantly than current practices, the way the

Table 3. Summary of Barriers to Implementation of the VMT Fee

Barriers	Solutions
1. Public Perception	
Resistance to Change	Public Education
Privacy	Technological Securities/Public Education
Emissions	Annual Emissions Fee
2. Technological	
Reliability	Small-Scale Trial Tests
GPS Accuracy	Sufficient for Polygon Method of Charging
3. Political	
Legislation	Educate Legislature on Benefits of VMT Fee/Public Education
4. Implementation Process	
Time Frame	Plan for 20 Year Transition Period
Implementation Cost	Annual Operating Fees Comparable to Fuel Tax

VMT fee is paid will. If the VMT fee is used to supplement the fuel tax (instead of replacing it), the issue of double taxation might surface. Proper public education must exist to help the public realize the benefits of the VMT fee.

As mentioned in the introduction, the nation's transportation system is not sufficiently funded. The public needs to be aware of the situation and know that the revenue generated from the VMT fee will go directly into each state's highway fund. This money will be used to benefit the public with better-maintained and more efficient roadways. A publicity campaign using television, radio, Internet and community meetings should be used to hear public's concern and offer the opportunity to answer questions. By explaining what the VMT fee will be used for, the betterment of the transportation network and ultimately a higher quality of life for the public, a government agency should be able to overcome public resistance to the new form of fee collection.

Privacy

Privacy for road users might be the largest issue that the GIS/GPS VMT fee implementation will face. The public may worry that the government will be able to track their every move while driving. It is important to note that GPS receivers do not send signals about location. The receiver's sole function is to pick up satellite signals and display coordinate information.

For the VMT fee approach to be accepted publicly it must be perceived as in no way intruding upon publicly accepted standards of privacy in the nation. Even though data collection of peoples' movements does not constitute an illegal infringement on their liberties, public perception of such a system would be difficult to change (3). The public must be made aware that all proposed VMT fee applications have safeguards to protect people's privacy.

The way to safeguard the privacy of individuals is to only transfer the necessary data. Within the VMT fee application process privacy must be preserved over three different domains: 1) while data is located within the vehicle's on-board computer, 2) during the upload procedure, and 3) while the data is stored at the collection center.

The purpose of the on-board computer with a GIS file is to make it possible to calculate the VMT fee on-board the vehicle. With these calculations taking place on the vehicle, the only data that needs to be transferred to the collection center is the amount the vehicle owner owes to each given jurisdiction. No information concerning distance traveled, time of travel or routes taken for a specific trip will ever be transferred from the vehicle. In addition, the computer can be programmed to erase the VMT data once it has been successfully uploaded to the collection center.

Privacy issues during the upload and collection process would be the main concern of the collection agency involved. Data transfer must be made secure whether the transfer occurs through radio frequency transmission or electronically. For security, data can be encrypted when it is sent and then read at the collection center. In addition, the fee information stored at the collection center must be protected against electronic attacks.

Technology exists today to secure the data during transfer and storage, so the privacy concern at this level should be easy to resolve. Most likely, the collection agency will be a private firm hired out by the government, which should help ease the concern of the general public about tracking because the government would not have direct access to a vehicle's VMT information.

Part of the fear concerning privacy and the GPS system is that the public does not understand how it works. Demonstration projects and testing will help dispel the myth that people have that the government will be able to track individual vehicles at any moment. The perception of privacy is a major issue that must be addressed before implementation of the VMT fee, but with proper technological safeguards throughout the system and proper institutional arrangements the public can be assured that privacy will be protected.

Emissions Standards

A strong point of the current fuel tax is that it charges more to those vehicles that are less fuel-efficient. Less fuel-efficient vehicles pollute the environment more than fuel-efficient or hybrid vehicles, and should have more of an economic burden. Under the new VMT fee all passenger vehicles would be charged the same amount for mileage driven. To overcome this discrepancy an annual emissions fee could be placed on the vehicle's registration that would be based upon fuel efficiency and emissions. This emissions fee would be used for environmental cleanup and the VMT fee revenue would be allocated to transportation infrastructure.

Technology

While all the technology exists today to implement the VMT fee system, it has never been applied to a road user fee system before. The scale (state-wide) at which the VMT fee would be implemented would necessitate that a system would be reliable. Current toll facilities require 99.9 percent accuracy on AVI technology (12). Accuracy equal to or better than that would be required to put into operation the GPS/GIS method of VMT fee collection. The GPS receiver and on-board computer need to be able to operate dependably for the lifespan of the vehicle. Transmission data needs to be collected without errors or loss of information. The billing process must be performed and sent to the proper customer.

The VMT fee represents a new system of transportation user fee collection. Fuel taxes are collected from the fuel distributors. There are a relatively few number of distributors in the nation, so fuel tax collection administrative duties are relatively simple. The VMT fee would collect revenues from each vehicle owner. The base of collection for the VMT fee is much greater and would require a large database and an information system that could process and keep track of individual vehicles. Such a database is possible, but it would require a large initial investment.

To obtain this type of large, system-wide reliability, trial tests need to be run. Small-scale trial runs of the entire VMT fee collection system would enable the technological glitches to be worked out before the statewide system is implemented. Oregon is proposing a three year testing period (15), while others believe that it will take between five and ten years to develop a system that will be adequately reliable.

GPS Technology

Today's GPS accuracy is sufficient for the polygon approach proposed earlier. The issue of two roads located close together, but falling in different jurisdictions has been raised. In reality this is a non-issue. If the jurisdictional boundaries are state borders, there are very few locations where roadways run parallel together on opposite sides of the border. Even if parallel roads do exist the amount of erroneous revenue collected from them would not be significant.

GPS accuracy does become an issue if the VMT fee were to be applied to different classifications of roadways. Error for such a system would have to be less than a meter for such a system to be feasible. GPS technology is not that accurate yet, but it is believed that this can be accomplished in the future.

Political

New legislation would be required to implement the VMT fee collection system. It is important that state legislators realize the benefits of the VMT fee system so that they are willing to change current practices. This process needs to coincide with the public education campaign so that legislators know they have the public support. If no public support exists, it will be difficult to create a new method for generating transportation funds. Lack of public support is the major contributing factor to why the fuel tax has not been raised to keep pace with inflation over the past decade.

Political support is necessary to the success of implementation of the VMT fee because there will be certain political lobbies against the institution of the VMT fee. The trucking industry could be opposed to such a system because the VMT fee will place more charges on large trucks than currently exists. These larger fees will be based upon the amount of damage commercial trucks do to the roadways.

Implementation Process

The implementation process of the VMT fee system itself presents many barriers to implementation. There are many factors on how a VMT fee will be implemented that must be addressed before legislation is passed. If these factors are overlooked, a successful VMT fee implementation will not occur.

Time Frame of Implementation and Avoidance of Double Taxation

If new technology is to be used, such as GPS receivers and smart card technology, a specified transition time period would have to be stipulated to phase in the new system. During this transition period both the VMT fee and fuel tax systems would be in operation. Preliminary research has concluded that a transition period of between 10 and 20 years is necessary for complete fleet rollover (3, 10).

The VMT fee could not instantaneously replace the fuel tax because the cost of retrofitting all vehicles with on-board computers is too high. Estimates for the cost of retrofitting a vehicle with a proper on-board computer and GPS receiver vary from \$350 to \$500 per vehicle. Legislation requiring that new vehicles be equipped with the on-board computer system would have to be passed. The new vehicles would pay the new VMT fee, while the older vehicles would pay road user fees under the current fuel tax system. Another way the VMT fee can be applied along side the fuel tax is to only apply the VMT fee to alternative fuel powered vehicles when they come to the market.

After the transition period has ended, vehicles not equipped with the necessary VMT fee technology could be required to have an annual odometer reading and pay a VMT fee. Another technique would be to charge a flat annual rate to those vehicles. This rate would be based upon average or slightly higher than annual VMT rates.

If radio transmission technology were used for the VMT fee, new vehicle owners would pay the VMT fee rate at the gas pump, and old vehicles would pay the current fuel tax rate. If another form of transmission were to be used for the VMT fee, then a rebate system would have to be applied to the new vehicle owners because they would be paying fuel taxes every time they refuel plus the VMT fee. The vehicle owners that have an on-board computer paying the VMT fee and fuel tax concurrently could receive a tax credit on state income tax returns. This credit would equal the amount of fuel taxes paid in a year. States that do not levy a state income tax would have to find another method of refunding fuel tax payments.

Administrative Costs

Regardless of the chosen method of application for the VMT fee, there would be large initial costs associated with the VMT fee. The odometer reading method would not require physical infrastructure, but would involve costs for training technicians to perform the odometer test and check for tampering. Any method involving GPS would involve initial physical infrastructure costs ranging from upload data stations to the collection center itself. Annual operating costs include personnel to collect bills, maintenance crews, data protection, and physical upkeep of the system involved. While initial costs are expensive for the VMT fee system, annual operating costs would not be much higher than the operating and collection costs of the fuel tax today (14).

RECOMMENDATIONS

The feasibility of the VMT fee depends on the method and purpose of collection. The only method that could be implemented currently is the odometer reading method. The following recommendations for the application of the VMT fee were determined by the based on conclusions drawn from benefits and barriers of VMT fee implementation. The recommendations are:

- An odometer reading VMT fee would be sufficient to supplement, but not replace, the current fuel tax.
- A more comprehensive system, like the GPS/GIS method of collection, would be needed to completely replace the fuel tax.

If politicians are searching for a way to increase transportation revenue without increasing the fuel tax, adding an odometer reading based VMT fee would be an option. Vehicles would have their odometer read annually at the time of emissions inspection and pay a fee with the vehicle's registration. Another method of reporting would be to have owners report annual mileage driven. The odometer reading technique is an approach to raise transportation revenue without adding new institutions and new technology to the tax collection system. A low price per mile (0.25 cents per mile) would be equivalent to raising the fuel tax by 5 cents per gallon with today's vehicle fuel efficiency.

Due to reporting and evasion problems that could arise with the odometer reading VMT fee method, it is not a good option to replace the fuel tax. Once properly tested, the GPS/GIS system for collecting VMT fees would be an acceptable approach to replacing the fuel tax. This method will accurately and directly charge users for road use on all vehicles, no matter how the vehicle is powered.

A simple statewide flat rate approach should be implemented first. The state of Oregon has estimated that a charge of 1.25 cents per mile would effectively replace the fuel tax. Each state, upon implementation, would recommend a price per mile to be charged. Once technology improves, and the GPS receivers

become more accurate, more specific pricing could be implemented. Specific pricing could be based upon road classification, peak hour travel, level of congestion, etc.

The GPS/GIS method of VMT fee collection is not ready to be installed today, as this technology must be tested first. Researchers estimate though, such a system will be feasible in the next 10 years. It is important to start looking at the possibility of implementing such a system so that legislative and institutional issues can be resolved during this time. By preparing now for the future, the transition between the fuel tax and VMT fee will be smoother.

GUIDELINES FOR IMPLEMENTATION OF VMT FEE AT THE STATE LEVEL

The implementation of a VMT fee user system will take the coordinated efforts of many government agencies. The implementation process is a long process, spanning 20 years or more, from the time the VMT fee is considered to when the fuel tax collection system is completely phased out. A general process for implementing the GPS/GIS method of the VMT fee at the state government level is presented in Figure 6. Each step requires time to complete necessary actions to assure successful implementation. The equipment testing and development of legislation should happen concurrently for the shortest possible implementation time.

It is important to begin exploring the possibilities of the VMT fee early because implementation of an operational user fee system will take at least 10 years. Currently, no guidelines exist for the entire implementation process of the VMT fee. The following guidelines were generated by the author. Guidance from the professionals contacted during the interview process and reviewing existing tax collection methods at the state level helped in the formation of these guidelines.

1. Create Task Force (3 years)

Before any decisions are made as to which VMT fee collection method should be implemented at the state level, a task force should be created to perform research and study all possible methods. The task force should be composed of delegates from many different areas within the state to provide fair representation of the state's population. Possible representatives include:

- State representatives;
- Representatives from city government;
- Metropolitan planning organizations;
- Academic researchers;
- Members from the department of transportation;
- Citizen's organizations;
- Special interest groups; and
- Department of finance.

The task force should develop a mission statement to guide them through the research process. One of the first research areas that should be looked at is the future revenue generated from the fuel tax. Once the future of the fuel tax revenues are known, the task force can decide on whether a VMT fee would be implemented to supplement or replace the fuel tax. The task force could then make recommendations to the state legislature on the proper method of VMT fee assessment for the state. If the task force concludes that an odometer reading VMT fee should be implemented, the process of implementation should proceed to the devise/propose legislation stage. Upon completion of the research and discussion, the task force should present their final conclusions to the state legislature and apply for funding of a small-scale pilot test.

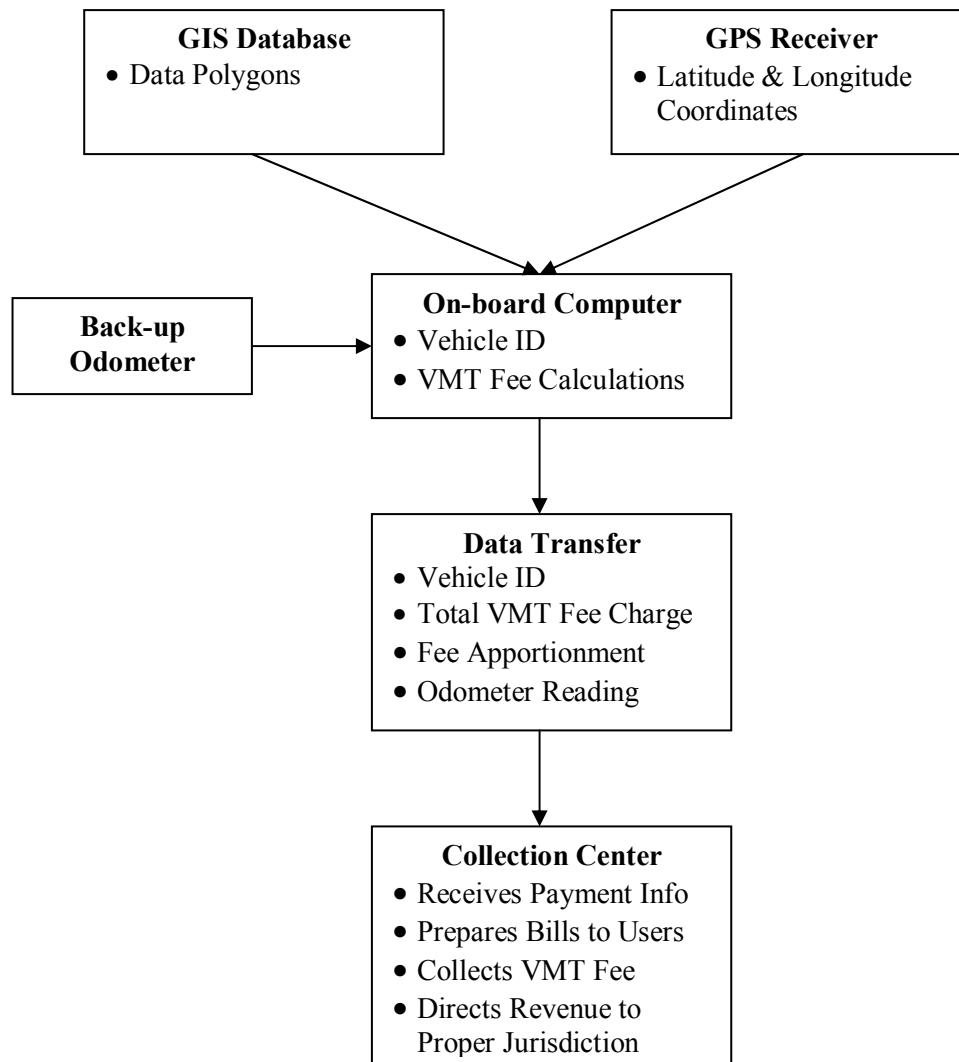


Figure 6. Implementation Process

2. Small Scale Testing (2-3 years)

Testing of the VMT fee technology before statewide implementation is key to the success of the end goal. The testing phase should last three years, and possibly up to five if major problems are experienced during testing. Testing of all phases of the VMT fee collection process is necessary during this time. Major areas that will need testing and refinement include the design of the on-board computer, fee calculation process, data transfer method, and system-wide reliability. Experimental vehicles should be placed on the roadway to test whether the GPS receiver is accurate and reliable in calculating the vehicle miles traveled. As testing is occurring, legislation for the implementation of the VMT fee should be devised.

3. Devise/Propose Legislation (2 years)

A new method of fee collection will ultimately need new state legislation. At the beginning of this process two elements are critical in the successful passing of legislation. First, find a political figure to

champion the cause in the state legislature. Second, use a publicity campaign program to educate the public and gain their support.

Hopefully, a member of the legislature that was a part of the task force will take up the cause and be the spokesperson for the legislation. During the process of devising state legislation, the authors of the plan should work with lawmakers and interest groups to draft a fair and passable bill. Major issues that must be addressed are the time frame of implementation and state policy while both the VMT fee and fuel tax are used concurrently.

A publicity campaign should take place to inform the public on the benefits of the VMT fee and how it will be implemented. This publicity campaign should use radio, television and other forms of media. In addition, town meeting should be held to hear the public's concerns and thoughts so that those issues can be addressed before implementation.

4. Physical/Institutional Installation (4 years)

A time of three to four years after legislation is passed is required for the installation of the physical infrastructure and new collection institutions. During this time new vehicles will start to be equipped with on-board computers and GPS receivers. The physical infrastructure required for data transmission will be installed statewide at designated locations. In addition to physical infrastructure, institutional organization should take place during this time. The collection agency should be formed and the database for the VMT fee should be created.

5. Start-Up with Concurrent VMT Fee and Fuel Tax

Once all the physical and institutional infrastructure is in place, the VMT fee collection method can be applied. Because only new vehicles will be equipped with the on-board computer system, the fuel tax will remain in place until the complete vehicle fleet rollover.

VMT fee collection will require interdepartmental cooperation among government agencies. The required state agencies to make the VMT fee operate properly are:

- State Department of Transportation;
- Department of Revenue;
- Auditor of Fuel Station Taxes (Department of Weights and Measures); and
- Enforcement Agency.

6. Full Implementation (20 years after initial implementation)

After 20 years, it is estimated that over 95 percent of the fleet will possess on-board computers and be compatible with the VMT fee. At this point the fuel tax will be phased completely out and the VMT fee will be the principle source of transportation revenue. Vehicles without on-board computers will be charged according to annual odometer reading or a flat fee.

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APPENDIX A

My name is Erik Guderian and I am currently a Master's of Engineering student at Texas A&M University studying transportation engineering. This summer I am involved in a mentor program, with James Wright (Minnesota DOT) as my mentor. As part of this mentor program, I am writing a research paper about new ways to finance transportation projects in the United States. I am specifically focusing on the application of vehicle miles traveled (VMT) fees in financing transportation. The VMT fee could be assessed in addition to or in place of the existing fuel tax.

In addition to performing a literature review of research being performed on VMT fees in the United States, I am conducting a survey to various members of state agencies that have been involved in VMT fee studies. The purpose of this survey is to assist me with knowing the opinion among state agencies about the feasibility of implementation of the VMT fee at the state level. The questions are designed to find out both the positives and negatives involved with VMT fee implementation. The results from this survey will be published in my paper.

If possible I would like to set up a time where I could administer this survey by phone. It should take no more than 10 minutes. If you are interested in assisting me please e-mail me back a convenient time for you when we could talk. If you would prefer to respond to the survey by e-mail the survey questions are listed below. Thank you for your time.

Sincerely,

Erik Guderian
e-guderian@ttimail.tamu.edu

VMT Fee Implementation Survey

Questions

1. Has your state (organization) considered implementing a road user fee based on vehicle miles traveled (VMT)?
 - a. If yes, would this fee be additional to the existing fuel tax or would it replace the fuel tax after implementation?
 - b. If no, how are you proposing to finance transportation in the future?
2. What benefits (if any) do you see towards the implementation of the VMT fee over the current fuel tax?
3. If the VMT fee was applied in your state, how would you propose assessing the fee?
 - a. At what rate would you assess the fee?
 - b. What method would be used to assess the fee (odometer reading, GPS, etc)?
4. What are the major barriers (political, public, technological, etc) facing the implementation process of the VMT fee?
5. What would be the time frame involved to phase in the VMT fee for all vehicles?
6. At the state level of government, which departments would have to be involved to make the implementation process of the VMT fee a success?
7. Do you have any other comments that would be helpful for consideration?

ERIK D. GUDERIAN

Erik D. Guderian received his Bachelor of Science degree in Civil and Environmental Engineering from Brigham Young University in April of 2002, where he graduated cum laude. While attending Brigham Young University, Erik was the recipient of the University Scholarship for four years. Erik was involved in many student organizations, including the student chapters of the Institute of Transportation Engineers, American Society of Civil Engineers, and the Tau Beta Pi, Utah Beta Chapter. As an undergraduate student Erik worked as an intern for the Utah Department of Transportation. He performed various activities at UDOT, including construction site inspection and material inspection. In addition, Erik also has worked as a surveyor and an AutoCAD technician for Western Land Surveying & Engineering located in Provo, Utah.

Erik is currently pursuing a Master of Engineering degree from Texas A&M University while working as a Graduate Research Assistant for Texas Transportation Institute (TTI) in its Center for Air Quality Studies. He is an active student member of ITE. Erik's career interests include geometric roadway design, transportation planning, public transportation, and signal operations.

PROPOSED TMC RESPONSE PROTOCOL TO SUSPICIOUS ACTIVITY AT HIGHWAY BRIDGES

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SUMMARY

Homeland security has become a very urgent topic in the United States in recent years. Although homeland security is a very broad topic, many of the security concerns exist in the transportation sector. Disruption of our nation's transportation system, where highway bridges are particularly vulnerable, would have serious impacts on the nation's economy and welfare. A bridge collapse on a major roadway could cause serious casualties as well as extensive damage to the existing infrastructure. The process of protecting these bridges may be thought of as being comprised of three main parts: detection of suspicious activity, assessment of its threat level, and response to the activity.

Because traffic management centers (TMCs) are already equipped to monitor traffic data on highway bridges, it seems to be a natural fit for TMC personnel to take on the extra role of aiding in the detection, identification, and response to suspicious activity. Also, a protocol for responding to suspicious activity should be established. This paper contains a discussion of available detection equipment, as well as recommended responses for TMCs to particular scenarios where suspicious activity is detected. The recommendations are meant to be general in nature, so as to be applicable to many situations.

To accomplish the goal of developing guidelines for TMC responses to suspicious activity, three main tasks were undertaken. First, surveys were sent to several TMCs throughout the U.S. Next, selected professionals in the areas of highway bridges, emergency management, traffic operations, and law enforcement were interviewed. Finally, documents submitted by the interviewees were reviewed.

Feedback from the surveys and interviews showed that many transportation agencies have thoughts as to possible ways to increase their security measures for highway bridges. Some of the agencies are working on plans to increase their monitoring abilities, although very few have actually begun the process of implementing them. No agencies surveyed have any procedures in place for identifying or responding to a particular threat.

The general guidelines developed throughout the course of this research include the following:

1. Co-locate with law enforcement
2. Co-locate with emergency management
3. Determine critical bridges
4. Explore methods to increase detection of threats at critical bridges
5. Explore methods to prevent access to critical bridge supports
6. Establish alternate routes in the case that a serious threat would warrant evacuations or the bridge being shut down
7. Assign a person or persons to monitor video of critical bridges during times of increased DHS threat levels (orange and red levels)
8. Increase inspections and patrols of critical bridges during times of increased DHS threat levels

Another finding from the surveys was that TMC operators do not have the authority to send responders to a potential threat detected in the field; only law enforcement officers have that authority. Therefore, the recommended response to most threats is to notify law enforcement, be it the state, county, or local police or the Coast Guard. Nonetheless, it is recommended that a protocol suitable for each TMC is developed in concert with the law enforcement agencies with the jurisdictions of the areas under surveillance.

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INTRODUCTION

Homeland security has become a very urgent topic in the United States in recent years. The U.S. and other nations have always sought ways to mitigate or stop terrorist activity, both domestic and abroad. However, since the September 11, 2001 World Trade Center collapse, the U.S. has increased its security measures in all areas. The Department of Homeland Security (DHS) was established along with a national color-coded terrorist threat level system to aid in preparing for possible terrorist acts. Because of the heightened awareness of terrorist attack preparedness, government and private agencies have raced to seek out new and effective ways to protect the infrastructure in the U.S.

Although homeland security is a very broad topic, many of the security concerns exist in the transportation sector. Disruption of our nation's transportation system would have serious impacts on the nation's economy and welfare. Because the transportation system is comprised of many parts, it is difficult to pinpoint the most vulnerable area. One area of major concern is highway bridges. A bridge collapse on a major roadway could cause serious casualties as well as extensive damage to the existing infrastructure. Also, if the destroyed bridge crossed a waterway used for shipping, then the damage done would include blocking the shipping route. This leads to the realization that some highway bridges may be more critical than others.

The process of protecting highway bridges may be thought of as being comprised of three main parts. First, a potential threat needs to be detected. This can be done in a variety of ways, including video surveillance and visual detection by bridge users. Second, the type or level of threat must be determined. For instance, a person wandering around in a private area may be less of a threat than an unoccupied rental truck parked beside a bridge support. Finally, something needs to be done about the potential threat. Some action must be taken to either remove the threat or mitigate possible damage that could result from a terrorist act.

The DHS states in a recent paper that the transportation sector does not have "appropriate security criteria on which to baseline its protection planning efforts, such as what conditions constitute threats for the sector, or standards for infrastructure protection or threat reduction." (*1*) Questions that need to be answered include who to contact when a threat is detected, who should respond to the threat, what actions should be taken by those responding, and in what order should respondents be notified. A recognized protocol for responding to detected terrorist threats and what role traffic management centers (TMCs) will play in this protocol needs to be established.

The mention of bridge security elicits a myriad of thoughts. One reason is that bridge security has many facets. Different agencies and departments all have particular roles in protecting our nation's infrastructure. Some of these roles are being increased whereas others are on the decline. The role of the TMC in bridge security is one that is possibly on the rise. The reason is simple; much infrastructure is already in place to accommodate an increased role.

SCOPE

Focus was limited to research on the technology and methods by which personnel in TMCs detect possible terrorist threats and respond to them. Research on detection of possible threats by law enforcement agencies was limited to their cooperation and association with TMCs. However, research on how and when TMCs and law enforcement agencies relay information to one another was within the scope of this project. The types of highway bridges studied included those over other highways as well as those over waterways. Research was performed on highway bridges exclusively in the U.S. and those spanning a U.S. border.

OBJECTIVES

The main objective of this research was to establish a general protocol by which personnel at TMCs can effectively respond to possible terrorist threats to highway bridges. Specific objectives were to:

- Speak with traffic management professionals to obtain knowledge on past, present, and future work in highway bridge security;
- Obtain information through surveys on the how personnel in TMCs detect, identify, and respond to suspicious activity at highway bridges;
- Review literature to gain background and technical information on infrastructure security;
- Reduce and refine the data obtained for analysis;
- Develop levels or tiers with which to categorize threats based on severity;
- Develop protocols with which to respond to the given threat levels; and
- Present the recommended protocols to traffic management professionals for review and critique.

STUDY DESIGN

The research for this study was performed in three phases. First, a survey was developed and sent to operators/directors of various TMCs across the nation. Second, professionals in Texas were contacted by phone for interviews covering the topic of this research. Finally, a brief literature review was performed to back up survey and interview responses.

After much of the information was gained pertaining to highway bridge security and the possible TMC role therein, general recommendations were developed to guide TMC personnel in becoming more effective to the security of highway bridges. Also, specific responses were developed to aid TMC personnel in determining a proper response to particular suspicious activities. It was noted, though, that a specific protocol for responding to suspicious activity should be made in collaboration with law enforcement agencies.

Surveys

The first phase of the research consisted of developing surveys with respect to highway bridge security. Questions asked on the surveys included what type of surveillance equipment the TMC used, how the TMC interpreted and responded to possible threats, and what equipment or techniques the TMC could use in the future. An example of the survey that was sent out is available in Appendix A – Survey Questions. A list of TMCs in different states was compiled with the hopes that personnel would take the time to complete the surveys. Since several other researchers studying TMCs were also interested in sending out surveys to many of the same TMCs, an effort was put forth to consolidate the surveys into one group of surveys sent to each TMC. Either the author or another researcher phoned each of the TMC contacts before sending out the surveys. In all, nine surveys were sent out to TMCs in eight states, and the results of the six returned surveys were compiled and are listed in the section on Findings.

Interviews

The author interviewed six professionals from three public agencies in Texas with regards to highway bridge security. Since the interviewees work for different agencies and departments, they provided many different views on how to detect, identify, and respond to suspicious activity. The position and agency for each interviewee is given in Table 1. Some sample interview questions are given in Appendix B – Interview Questions, but the questions varied for each interviewee depending on their area of expertise.

Table 1. Interviewee Positions and Agencies

Position	Agency
Deputy Director of Bridge Division	Texas Department of Transportation
Director of Maintenance Division	Texas Department of Transportation
Director of Traffic Management Section, Traffic Operations Division, Houston District	Texas Department of Transportation
Director of Traffic Operations, Houston District	Texas Department of Transportation
Captain	Houston METRO Police
Director	Harris County Office of Emergency Management

Literature Review

Very little substantial information on the topic of bridge security was found in the literature. Therefore, the literature reviewed during this study mostly consisted of intra-departmental memos, reports, and guidelines given to the author by the interviewees.

BACKGROUND

When terrorists plan an attack, they try to pick a target that would cause the greatest amount of damage for a particular type of structure. A prime example of this is the September 11, 2001 attacks. The targets were the tallest buildings in New York City, the U.S. military headquarters, and another yet unknown target, possibly Air Force One. Therefore, if terrorists were to plan to attack transportation facilities, a highway bridge or tunnel would be a prime target. Also, they would most likely try to maximize the damage of the attack by picking a very important structure. Because of this, the highway bridges that are the most important, or critical, need to be analyzed for protection before those that are less critical.

Two types of highway bridges were under consideration during the study: those over other roadways and those over waterways. Both types may be equally likely to be the target of a terrorist attack, and the importance of the bridge does not depend on whether it is a fixed bridge, suspension bridge, or cable-stay bridge. For a bridge to be critical it must meet certain requirements. The first step in the Texas Department of Transportation's (TxDOT) five-step approach to transportation security is to identify the state's most critical bridges. (2) To do this, a Texas Bridge Criticality Formula was developed:

$$\begin{aligned}
 & \left[\frac{\text{Truck ADT} \times \text{Truck ADT Factor}}{\text{Max Truck ADT}} + \frac{\text{ADT} \times \text{ADT Factor}}{\text{Max ADT}} + \frac{\text{Detour} \times \text{ADT} \times \text{Detour Factor}}{\text{Max Detour} \times \text{Max ADT}} \right. \\
 & + \frac{\text{Intersect Rt. ADT} \times \text{Intersect Rt. Factor}}{\text{Max Intersect Rt. ADT}} + (\text{Interstate Intersection} \times \text{Interstate Intersection Factor}) \\
 & + (\text{Navigation Importance} \times \text{Navigation Factor}) + (\text{International Importance} \times \text{International Factor}) \\
 & \left. + (\text{Military Importance} \times \text{Military Factor}) \right] \times \frac{\text{Replacement Factor}}{8},
 \end{aligned}$$

where: Each of the “factors” is a numeric factor, nominally between 0 and 1, that relates the relative importance of the respective criterion to the other criteria in the formula;

Each of the “Max ADTs” is the maximum ADT for any bridge in the state;

Interstate Intersection = 1 if both main and intersecting routes are Interstate Highways, or 0 if one or both are not Interstate Highways;

Navigation Importance = 1 if the bridge requires a Coast Guard permit based on Item 38 in the Bridge Inspection Data Base (BIDB), or 0 if no Coast Guard permit is required;

International Importance = 1 if the bridge borders on Mexico based on Item 98 on the BIDB, or 0 if it does not;

Military Importance = 1 if the bridge is located on the Strategic Highway Network based on Item 100 in the BIDB, or 0 if it is not;

Replacement Factor = Structural Complexity (low = 0, medium = 1, high = 2, Item 43 of the BIDB) $\times$ Span Length Factor (<150' = 0, 150'-300' = 1, >300' = 2, Item 48 of the BIDB). (2)

SUSPICIOUS ACTIVITY

Before suspicious activity can be definitely detected, interpreted, or responded to, it must be defined. Suspicious activity in this paper refers to many things, which includes, but is not limited to:

- A person or persons in a restricted area;
- A vehicle (car, truck, van, boat, etc.) in a restricted area;
- A vehicle either stopped or going very slowly on a bridge;
- Any package, large or small, of unknown contents on or near a bridge;
- A person or persons acting nervous or “strange;” or
- A person or persons studying a bridge’s supports.

Basically, suspicious activity relates to any person, thing, or event that appears out of the ordinary or that is a possible threat. A response to suspicious activity cannot be made without it first being detected. Also, a response should not be made without the best interpretation as to what the suspicious activity is. A person fishing in a restricted area under a bridge can be considered suspicious activity; however, the response to shut down the bridge, reroute traffic, deploy the Haz-Mat teams and bomb squads, and bring in air support may be a bit of an overzealous response. On the other hand, that same person may get up and walk away while the box explodes, damaging the bridge and possibly causing casualties.

An example of a serious threat with a drastic response and an odd outcome can be found in Houston, Texas. On March 21, 2003, the Fred Hartman Bridge on Texas State Highway 146 over the Houston Ship Channel was shut down. At approximately 10:30 a.m., a tugboat crew witnessed a boater place a cardboard box on the bank near a bridge support and leave. The tugboat crew immediately notified the Coast Guard, and the FBI was notified. Also, the bridge and part of the ship channel were shut down to all traffic, and motorists were advised to take an alternative route. Finally, the Coast Guard was able to use an X-ray machine to determine the box’s contents. A cat had been “buried at sea” and left under the bridge. The bridge and ship channel were reopened about 12:15 p.m., and no one was able to determine who was responsible for leaving the cat-in-a-box at the bridge. (3)

Detection

Obviously, the best way to protect our nation’s infrastructure from terrorist acts is to completely discourage terrorists from attacking. However, this is an unrealistic goal. The next best option would be to stop an act before any damage occurs, and the last possibility would be to design the structure to

withstand an attack. Although the last two options are not 100 percent achievable, they are possible to a certain degree. Research has recently begun on designing bridges to withstand manmade events as well as natural events. (4) Reinforcing highway bridges to stand up to an explosive device is a real option, though special explosive charges, such as shaped or cutter charges, can still pose a serious threat. Therefore, a high priority must be placed on the detection of possible threats to highway bridges to reduce the chances of an attack being carried out in full.

Several methods of detection are available, and many would not require major retrofitting of the existing structures. Since TMCs are already monitoring traffic flows on major freeways and arterials, it seems a natural fit to include them on the list of agencies in charge of detecting possible threats. However, TMCs are not generally set up to detect threats of this nature.

The three most common methods of detection of traffic incidents for TMCs are closed-circuit television (CCTV) surveillance cameras, inductive loop or video traffic detectors, and electronic toll tags in individual vehicles. The three methods are described below.

Currently, most cameras operated by TMCs that provide video of bridges only do so with respect to the traffic flowing over them. Cameras are not located underneath highway bridges (5,6) where a terrorist may strike. An example of a CCTV camera is provided in Figure 1. These cameras can usually be panned, tilted, and zoomed, and relay only visual data back to a TMC. Many TMCs employ numerous cameras. For instance, TranStar, the TMC in Houston currently has over 300 cameras in operation throughout the greater Houston metro area, (7) and TransGuide in San Antonio uses 140 cameras. (8) With so many cameras, TMC personnel cannot watch all locations at once. Instead, they use two approaches. First, if an incident has been detected, an operator can turn on a camera that can video the section of roadway where the incident was detected. Second, the operator may set the system to switch between a number of cameras every few seconds. In either of these methods, the TMC personnel are not very likely to detect any suspicious activity.



Figure 1. TMC Closed-Circuit Television Camera for Visual Traffic Information

For incident detection, the TMC personnel generally rely on traffic data provided by inductive loop detectors or by electronic toll tags. (9) The loop detectors and video detectors relay traffic data such as vehicle speed back to the TMC. When traffic speeds drop below normal operating speeds, the system triggers an alarm. Reduced speeds are normally the result of a traffic incident, such as a crash or other blockage. Figure 2 is an example of a street with inductive loop detectors, and Figure 3 shows a camera designed to detect traffic, both of which can transmit data to a TMC.



Figure 2. Inductive Loop Detectors in Pavement for Traffic Flow Data

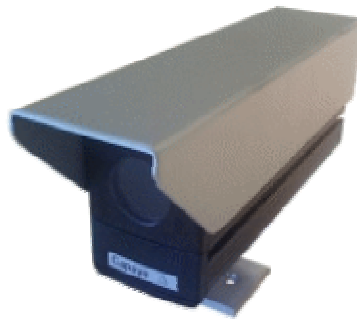


Figure 3. Video Traffic Detector – CAPsee DVS Image-sensor, Capsys

The other detection method involves the use of electronic toll tag readers located throughout the detection area. These readers can detect when a particular vehicle travels between the readers and relays the information to the TMC. The speed of the traffic can be calculated by the distance between the readers and the time it takes for the vehicle to travel between them. Figure 4 shows an electronic toll tag which is detected by electronic toll tag readers. The readers then transmit traffic data to a TMC. Houston TranStar is an example of a TMC that uses this type of traffic incident detection. (Z)

When trying to detect possible terrorist activity, other methods of detection are available. One method would be to implement the same type of CCTV cameras currently being used for freeways and arterials, except locate them at positions that could monitor activity underneath bridges. Also, these cameras could monitor access points through which a person or vehicle would have to travel to pose a threat. Another method involves the use of motion detectors. These motion detectors could activate an alarm in the TMC to alert the personnel to suspicious activity in that area. The only agency that responded to the surveys stating that they employ motion detectors is Caltrans in California. (2) Even very simple methods could increase the effectiveness of suspicious activity detection, such as increased lighting. A thermal imaging

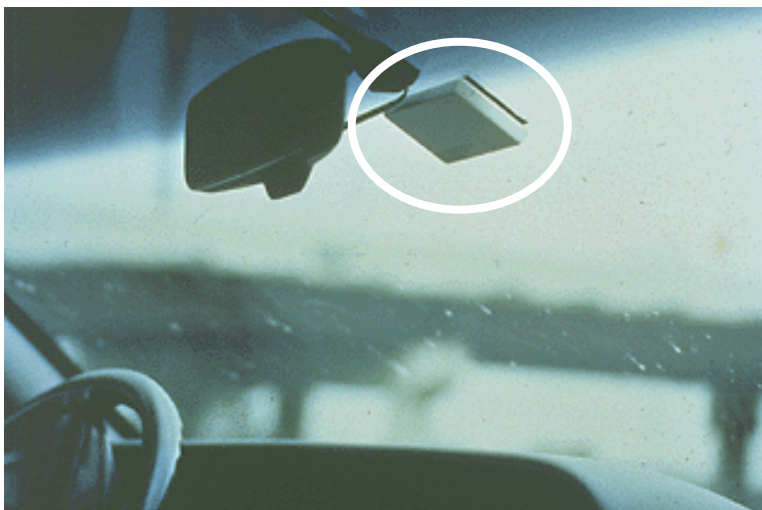


Figure 4. Electronic Toll Tag on Windshield

system would provide a heat signature of anything out of the ordinary, and increased law enforcement patrols could also be a benefit to detection. (10)

Interpretation of Suspicious Activity

When a suspicious activity is detected, the next step should be to identify, or interpret, the activity. Is it a threat? How serious is it? If it is a bomb, what could the ramifications be if it exploded? These are serious questions that must be answered. A proper response to any suspicious activity cannot be made unless the type of threat it poses is properly identified. Currently, most, if not all, TMCs rely on local law enforcement to identify suspicious activity on highway bridges as well as anywhere else the TMC may detect it. (5) If a response is to be made quickly, the law enforcement personnel must be made aware of the possible threat even quicker. A question then arises; if law enforcement is not co-located within the TMC, should the TMC personnel be trained to assess the severity of possible threats so as to reduce identification time?

Response to Suspicious Activity

After a possible threat has been detected and identified through the best possible means, a response should be immediately initiated. Currently, the only response that TMC personnel have to possible threats is to notify law enforcement, regardless of the seriousness of the threat. For most TMCs, this is a questionable process because of the possibility of poor communication with the law enforcement officials. However, some TMCs employ law enforcement within the building. This provides immediate assessment of the threat by the responding agency. The enforcement agency on staff can immediately dispatch the proper personnel, teams, vehicles, or equipment from the confines of the TMC. Examples of TMCs with this ability include TranStar in Houston, TransGuide in San Antonio, Capital Region TMC in Albany, Hudson Valley TMC in Poughkeepsie, New York, the East Baton Rouge TMC, and TMCs in New Jersey to name a few. (11) Figure 5 is a picture of a police officer sharing the TMC in San Antonio.

At TMCs that do have law enforcement co-located in the building, response protocol is varied. Most, if not all, have guidelines to follow when an incident occurs. However, these guidelines generally refer to traffic incidents. Some law enforcement agencies have established protocols to follow when responding to possible terrorist threats. Others have rules under consideration.



Figure 5. Police Co-Location at TransGuide in San Antonio

At Houston TranStar, the Harris County Office of Emergency Management (OEM), Harris County Sheriff's Office personnel, and METRO police are all located within the same TMC with TxDOT. This arrangement of agencies all working together can create a very rapid and organized response to any incident. The Harris County OEM gathers information on what response each agency is making and disseminates that information to the other agencies so as to reduce any chance of redundant responses. (12) Also, this level of coordination aids in directing the proper authorities from each area to the event. Specialized teams, such as SWAT, Haz-Mat, and bomb squads, can all work together to respond to a possible threat. The OEM also helps to organize evacuations due to natural events such as hurricanes or floods. This evacuation response protocol is very beneficial when trying to organize an evacuation needed because of a terrorist act or threat.

SURVEY FINDINGS

In order to obtain information on the state-of-the practice in the detection, interpretation, and response of suspicious activity, surveys were sent to nine representatives of TMCs throughout the U.S. Six of the surveys were returned, although little information was retrieved from these surveys. The responses were similar among agencies for each question, and a summary of those responses is shown in Table 2. Although the representative from the Washington State Department of Transportation (WSDOT) did not answer any individual questions on the survey, he did make comments about the agency's role in detecting, identifying, and responding to suspicious activity. The response from WSDOT was the following:

"Security enforcement is primarily a law enforcement function, so it primarily falls on the Washington State Patrol (WSP). WSDOT does work with WSP in a supporting role. We would prefer not to document our role in this regard. Generally speaking, many of WSDOT personnel are trained or instructed to be alert to unusual activities and to work with WSP for response."

Question five on the survey was unique; it was a question on what responses TMC would make based on the detection and identification of particular threats. Because the survey respondent was required to fill in a blank as to the response they would take, the results of that question are summarized separately in Table 3. In the table, specific suspicious activities are located in the left column, and the responses the TMC personnel would take to each activity are presented in the column on the right. A legend denoting what each number represents is given in the bottom of the table. It should be pointed out that not all survey respondents assigned a number to every activity. Numbers that appear with a slash ("/") between them represent two different responses the personnel would take at a given TMC. Although responses to this question were very similar between agencies, the numbers are not assigned to any particular TMC, so as to provide some level of anonymity.

Table 2. Responses to Survey on TMC Role in Highway Bridge Security

Survey Question	St. Louis	Detroit	Long Island	Houston	San Antonio	San Diego
1. What, if any, equipment does your agency employ to detect suspicious activity at highway bridges?	CCTV for Freeway and Incident Management purposes.	Utilize CCTV at international bridge crossings for traffic delays and security. None at other	CCTV, patrols, and bridge personnel.	None at this time. Plans for CCTV equipment under bridges.	Confidential	California Highway Patrol (CHP)
2. How much (%) does the TMC rely on law enforcement for possible threat detection?	95 %	100 %	80 – 90% at least.	100 %	25-50 %	CCTV. CHP has motion and video detection.
3. What, if any, procedures does the TMC have for identifying/classifying suspicious activity?	No set procedure for identifying.	None.	None.	None at this time.	Camera observations, public calls, police observations	Based on CHP criteria. Activities relayed to the CHP for their review.
4. What, if any, procedures does the TMC have for responding to suspicious activity?	Missouri Highway Patrol is notified to respond.	None, except if a facility gets damaged.	Notify law enforcement agencies or the US. Coast Guard.	None at this time.	Let police handle situation.	Information is shared directly with CHP at the TMC.
6. What other possible threats could the critical highway bridges in your city/county be subjected to?	Light rail and pedestrian bridges.		Drawbridges that could be sabotaged.		Haz-Mat incidents, vehicle fires, flooding	Earthquakes Some structures have seismic detectors.
7. What other responses could the TMC make to possible threats with the current technology in place and with new technology?	Can adjust signal timing for diversion routes. – Dynamic response to signal timing, DMS.	None.	Increased sensing equipment & CCTVs.	Automated Detection Systems, CCTV under bridge	Explosive detection systems, machine vision	More video and motion sensitive detection – infrared

Table 3. Summary of Responses to Survey Question Number Five

Suspicious Activity	Response
Person fishing under bridge	4, 2, 2, 2, 4
Person walking under bridge	4, 2, 1, 2, 4, 4
Person with bag/object under bridge	4, 4, 6, 4, 4, 4
Person “doing something” under bridge	4, 4, 6, 4, 4
Car stopped on bridge	3/4, 2, 3, 4
Car stopped on bridge and occupant(s) leaving	3/4, 6, 3/4, 4, 4
Car stopped under bridge	4, 4, 2, 3, 4, 4
Car stopped under bridge and occupant(s) leaving	4, 4, 6, 3/4, 4, 4
Truck or van stopped on bridge	3/4, 4, 2, 3, 4, 4
Truck or van stopped on bridge and occupant(s) leaving	3/4, 4, 6, 3/4, 4, 4
Truck or van stopped under bridge	4, 4, 2, 3, 4, 4
Truck or van stopped under bridge and occupant(s) leaving	4, 4, 6, 3/4, 4, 4
Vehicle crossing the bridge very slowly	4, 3/4, 2, 1, 4
Vehicle crossing the bridge in quick repetition	4, 4, 6, 1, 4
Boat stopping/stopped by bridge pillar	4/8, 2, 6, 2, 4
Boat occupants exiting onto the bank under bridge	4/8, 4, 6, 4, 4
Boat crossing beneath the bridge in quick repetition	1, 4, 6, 2, 4
Call-in bomb threat	4/5, 4/5/7, 5/6, 4/5, 4/5
Legend: 1. Do nothing, ignore 2. Do nothing, but continue to monitor 3. Send HERO/HELP/etc. to check out 4. Call local police/sheriff 5. Use DMS messages to shut down bridge and reroute traffic 6. Refer to Highway Patrol 7. Evacuate building 8. Call Coast Guard	

One of the comments received by a few of the interviewees is that they are not sure whether it is more important to increase detection and response efforts to possible threats or to increase response planning for events following an attack. That comment should definitely be noted, since it would be unreasonable to think that one would be able to detect and prevent any attack. This comment was made because it is obvious that many terrorists are willing to give their lives for an attack. An attack such as this would probably limit or negate any time for detection and response. One would simply arrive and explode. Planning for events following an attack, such as alternate route planning and evacuation protocol, should be considered; however, if an agency would be able to prevent an attack from occurring, the result would be much more positive.

RECOMMENDATIONS

After a review of the interview responses, survey responses, and documents provided by professionals, several recommendations to how TMC personnel detect, identify, and respond to suspicious activity at highway bridges were developed. It should be noted, though, that some TMC personnel have more authority than personnel at other TMCs. Therefore, some of the recommendations may not be feasible for all TMCs. These particular recommendations are written for the TMC personnel that do have authority to implement them. As mentioned earlier in this report, many TMCs have police co-location, which gives the TMC as a whole more authority. A summary of the recommendations is below, and these guidelines are detailed in the paragraphs that follow.

General Recommendations

1. Co-locate with law enforcement

A TMC that contains law enforcement personnel as well as Department of Transportation (DOT) employees will greatly decrease the response time for any possible response. Also, police co-location will aid in determining the type of response necessary for a particular suspicious activity. Law enforcement personnel are trained to watch for specific characteristics in suspicious persons and objects. Along with this, they can generally make a better assessment of an individual or his/her actions than the general public as to whether the person poses a serious threat. If law enforcement personnel are present in the TMC, they can monitor activity the instant it is detected and dispatch the appropriate responders. Since DOTs do not have the authority to dispatch law enforcement officers, co-location becomes a very important factor in reducing response times.

2. Co-locate with emergency management

Emergency management personnel are also very important in reducing response times to threats as well as attacks. The emergency management personnel coordinate the different agencies in the response; therefore, everyone involved will know their roles. If co-location with emergency management officials is not possible, a tight working relationship is mandatory. No matter whether an attack is possible or one has already occurred, just a few seconds can make a huge difference as to how much damage a bridge will be subjected to or how many people are injured.

3. Determine critical bridges

Instead of focusing attention on all of the bridges in the area, concentration should be placed on only those that are more critical than others. In other words, highway bridges that serve greater purposes should have higher priority than those where an attack would not create as serious a danger. The reason is twofold. First, as mentioned earlier, a terrorist would try to take out a bridge that would cause the greatest amount of damage and death. Second, by focusing on critical highway bridges, money used in protection will not be allotted to unnecessary areas.

4. Explore methods to increase detection of threats at critical bridges

Many methods are available to increase suspicious activity detection at critical bridges. The first line of defense should be normal CCTV cameras located in positions to see all of the bridge supports. Also, cameras may be placed so TMC operators can monitor under-bridge access points. If the TMC does not have personnel resources to watch the TV monitors constantly, another type of detection must be installed. Infrared detection systems can detect movement in night or day. However, motion sensors should not be placed in areas in which false alarms would be a regular problem. Birds whose nests are under the bridge may be one concern for false alarms. Also, CCTV cameras and other detection equipment should not be conspicuous. Placing detection equipment in plain sight would render it useless, since anyone wishing to cause damage would obviously avoid it. Another increase to detection of suspicious activity is as simple as increasing lighting over and/or under the bridge.

5. Explore methods to prevent access to critical bridge supports

This recommendation may not be feasible for many bridges, e.g., some bridges have parking areas underneath. However, if the destruction of the bridge would cause a greater cost to society than the benefit of allowing underneath access, the possibility of preventing access under the bridge may be considered.

6. Establish alternate routes in the case that a serious threat would warrant evacuations or the bridge being closed

In the event that an attack on a highway bridge is carried out, traffic must take alternate routes. That is why a plan should be devised to show other paths that traffic may follow. Planning for alternate routes should be done during the first stages of securing highway bridges. If detection equipment has not been installed, if it does not detect a threat, or if no time exists to respond to a threat, then unfortunately, the only available response is to reduce the traffic chaos caused by an attack. An alternate route plan would help mitigate this chaos.

7. Assign a person or persons to monitor video of critical bridges during times of increased DHS threat levels (orange and red levels)

During increased alert levels, TMC operators should be more vigilant in monitoring the critical bridges under their watch. Therefore, it is recommended to staff at least one person to monitor activity on or under critical bridges. This person would not be focusing on traffic operations, but on the safety of the highway bridges. This person should also be trained in what type of activity to look for to help in assessing the type of threat that may arise.

8. Increase inspections and patrols of critical bridges during times of increased DHS threat levels

Although having someone monitor the critical bridges from the TMC could help detect a threat, inspections of the actual site would help in the areas that are not visible to the CCTV cameras. Also, if a terrorist were to plan an attack, they may be deterred when they discover someone is patrolling the area. Another benefit would arise when a threat is detected from the TMC. An inspector may just so happen to be very near that bridge and could be the first to arrive and assess the situation.

Responses to Suspicious Activity

Based on survey responses, interview responses, and a review of the literature, Table 4 was developed as a list of actions that are recommended for the respective activities. The reasoning behind the recommended responses is discussed in the next few paragraphs. For any suspicious activity listed, a more serious response may be initiated based on an assessment of the actual threat that the activity poses.

It should be noted, though, that all activities are to be monitored closely by the TMC. Also, these recommendations are only meant to be guidelines. They should be tailored to fit the individual needs and abilities of a particular TMC *with the cooperation of all parties involved*, including law enforcement, the U.S. Coast Guard, and bridge personnel.

Table 4. Recommended Responses to Suspicious Activity

Suspicious Activity	Response
- Person fishing under bridge - Boat crossing beneath the bridge in quick repetition	Do nothing, but continue to monitor
- Person walking under bridge - Car, truck, or van stopped on bridge - Vehicle crossing the bridge very slowly - Car, truck, or van stopped on or under bridge and occupant(s) leaving - Vehicle crossing the bridge in quick repetition - Boat occupants exiting onto the bank under bridge - Bomb threat	Notify local police/sheriff/highway patrol
- Boat stopping/stopped by bridge pillar - Boat occupants exiting onto the bank under bridge - Bomb threat	Notify Coast Guard or law enforcement with waterway authority
Bomb threat	Close the bridge and reroute traffic.

For a person fishing under a bridge and a boat crossing in quick repetition, the recommended response is to do nothing except continue to monitor the activity with the CCTV cameras. Although the person that is fishing may be in a restricted area, no response is recommended unless the person is in an area that may be hazardous to himself/herself or an area in which the person may be able to do damage with little effort. Such damage would include breaking a light, CCTV camera, or other detection equipment. As mentioned earlier, though, if the TMC personnel have any suspicion that the person may be there for any reason other than fishing, a more serious response may be necessary. For bridges over navigable waterways, a boat that is crossing back and forth in quick repetition will most likely be transporting cargo. One possibility is that an attack planner may be studying the bridge; however, it is not likely that one would do so in such a conspicuous manner. Nonetheless, it is recommended that the boat be closely monitored from the TMC.

Most suspicious activity scenarios warrant law enforcement control. A law enforcement agency should be notified when a vehicle is either stopped on a bridge or crossing it very slowly. Optimum camera location should help in assessing the situation by being able to focus on the occupants of the vehicle. Probably the most controversial situation-response combination is to notify law enforcement for a person walking under a bridge versus just monitoring a person fishing. The reason that a person walking underneath a highway bridge is a potentially more threatening situation is because the person that is fishing has a “reason” to be there. Although the area under the bridge may be restricted, that person most likely does not pose as serious a threat to the bridge or its users. Notifying law enforcement for a vehicle that is stopped under a bridge is a response that should be obvious. However, if the vehicle is above the bridge deck, and the occupants are leaving, law enforcement should be notified for two reasons. First, the

vehicle occupants may be leaving a car bomb on the bridge. Second, the occupants are putting themselves at risk by walking or running on most highway bridges. Situations such as these would benefit greatly from having law enforcement co-located in the TMC. That way, the law enforcement personnel could make the assessments and the dispatched units may take the situations more seriously.

Law enforcement should be notified when a vehicle crosses a bridge in repetition. Virtually no benign reasons exist for this behavior, so this activity should be investigated. As the old adage goes, it is always better to be safe than sorry. Occupants of a boat or ship that exit onto the bank under a bridge are highly suspicious. The reason may be simply that the boat is sinking, or it may be that they are initiating an attack on the structure. Either way, law enforcement should be notified. Also, it is obvious that law enforcement should be notified for a bomb threat. Specialized teams, such as a bomb squad, most likely will be dispatched at the enforcement agency's discretion.

If the highway bridge traverses a waterway under the authority of the United States Coast Guard, they should be notified when a boat is stopping by a bridge support, when the occupants leave the vessel, or when a bomb threat has occurred. Other officials should be notified as well, such as a port authority or any agency that has jurisdiction over the waterway. Except for a highly unusual case where a dock is located near a bridge support, no reason exists for a boat to stop there. If a dock is located near a support, it is highly recommended that it be moved so as to remove a prime target for an attack.

The only scenario in which the recommendation is to shut down the bridge is in the case of a bomb threat. Whether the threat is from a phone call or a suspicious package, it is recommended that the bridge be shut down until an investigation by the appropriate authorities is complete. Even though the cat-in-a-box example turned out to be harmless, the protocol was appropriate. A city can withstand a delay of a few hours when the safety of many people is in question.

One major difference between some survey responses and the recommended responses is the use of courtesy patrols. It is at no time recommended that courtesy patrols are sent to investigate suspicious activity. The risks are too high because of two main reasons. First, a person on a courtesy patrol is neither trained nor equipped to handle a threat. Second, having a courtesy patrol respond only takes away from precious time that law enforcement could use to respond to a threat. It is for these reasons that law enforcement personnel are recommended to be the only respondents to the scene of a suspicious activity on a highway bridge.

Validation of Recommendations

These recommendations were modified after a review by TMC personnel. Both the general recommendations and the recommended responses to suspicious activity were sent to the same TMC personnel that responded to the initial surveys. Questions asked about the general recommendations included:

- Does your TMC already do this?
- Is this feasible?
- Is this practical?
- Would this be effective?
- Is it being considered by your TMC?

For the recommended response protocols, the questions on the survey were:

- Is this feasible?
- Is this practical?
- Would this be effective?

Results were obtained from four agencies, and the responses were similar based upon the physical abilities of the TMC. For example, law enforcement co-location is only feasible where room exists within a TMC. For the most part, the recommendations were regarded as feasible, practical, and effective with two main discrepancies. First, two of the agencies responded by saying that continued monitoring of suspicious activity is infeasible, impractical, and ineffective. The basic reason given for these responses is that it would be a waste of time and money. Second, it was pointed out by two of the agencies that the closure of a bridge would have to be decided upon by law enforcement officers. Nonetheless, the recommended responses were not changed. That is because they are recommendations based on safety and security, not funding. One major change was made, though. An initial recommendation was to send courtesy patrols to investigate certain events. After more research and responses from two of the responding agencies, the recommended response was changed to notification of law enforcement personnel. Even with the specific recommendations in this paper, a proper response protocol should be developed in concert with all possible responding agencies. A truly effective protocol would have to be developed around the particular abilities of the TMC.

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APPENDIX A – SURVEY QUESTIONS

This section lists the questions to be included on the survey sent to TMC personnel. Although the questions may be slightly reworded to correct any ambiguity before the survey is sent out, the information sought for each will not change.

1. What, if any, equipment does your agency employ to detect suspicious activity at highway bridges?
2. How much (%) does the TMC rely on law enforcement for possible threat detection?
3. What, if any, procedures does the TMC have for identifying/classifying suspicious activity?
4. What, if any, procedures does the TMC have for responding to suspicious activity?
5. For each suspicious activity, write the number of the response that the TMC would most likely take, assuming it was the first to detect the activity. Some activities may require more than one response. (All areas are assumed to be no-trespassing areas.)

Suspicious Activity

Response

☐ Person fishing under bridge	1. Do nothing, ignore
☐ Person walking under bridge	2. Do nothing, but continue to monitor
☐ Person with bag/object under bridge	3. Send HERO/HELP/etc. to check out
☐ Person “doing something” under bridge	4. Call local police/sheriff
☐ Car stopped on bridge	5. Use DMS messages to shut down bridge and reroute traffic
☐ Car stopped on bridge and driver leaving	6. Other response (describe)
☐ Car stopped under bridge	
☐ Car stopped under bridge and driver leaving	7. Other response
☐ Truck or van stopped on bridge	
☐ Truck or van stopped on bridge and driver leaving	8. Other response
☐ Truck or van stopped under bridge	
☐ Truck or van stopped under bridge and driver leaving	
☐ Vehicle crossing the bridge very slowly	
☐ Vehicle crossing the bridge in quick repetition	
☐ Boat stopping/stopped by bridge pillar	
☐ Boat occupants exiting onto the bank under bridge	
☐ Boat crossing beneath the bridge in quick repetition	
☐ Call-in bomb threat	

6. What other possible threats could the critical highway bridges in your city/county be subjected to?
7. (Two parts) What other responses could the TMC make to possible threats with the current technology in place and with new technology?

APPENDIX B – INTERVIEW QUESTIONS

This section lists some of the questions for interviewees. Depending on the person interviewed, actual questions varied greatly.

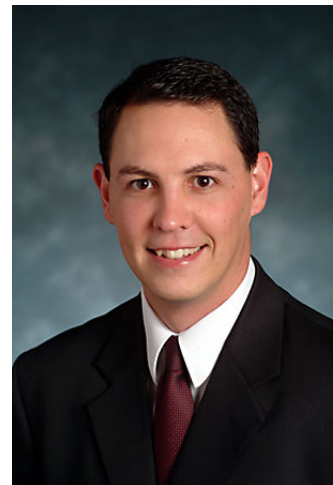
1. What is your background/experience in infrastructure security and/or TMC operations?
2. How much emphasis has been placed by your agency on highway bridge security?
3. What procedures are in place to detect or respond to suspicious activity?
4. What work are you familiar with that is currently addressing the issue of highway bridge security or other infrastructure security?
5. What role do you think TMCs *currently* play in detecting, identifying, and responding to suspicious activity at highway bridges?
6. What role do you think TMCs *should* play?
7. Do you see a need for an established protocol for TMC personnel in identifying and responding to suspicious activity?
8. What are your personal thoughts on the future of highway bridge security, including detection technologies and response measures?

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APPLYING INTERMODAL DISTRIBUTION PROCEDURES TO A FUTURE TRANS TEXAS CORRIDOR FREIGHT SYSTEM

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SUMMARY

The adoption of NAFTA has resulted in increased levels of trade between the United States, Mexico, and Canada. The state of Texas serves as the primary gateway between Mexico and the U.S, and as a result, Texas transports more international freight than any other state. Unfortunately, the increased freight demands have led to growing traffic congestion problems in Texas. Statistics show that current trends of widening roads and freeways will not be sufficient or appropriate to handle the both the projected population and international trade boom in the state of Texas. Freight traffic caused by heavy trucks contributes significantly to urban traffic congestion, and unless alternative modes of freight transport are undertaken, truck volumes may become unbearable in the future.

The new Trans Texas Corridor plan is currently proposing to address this problem in the future by creating a freight shuttle system that will move containerized freight more quickly and efficiently between major cities. However, it remains undetermined how a future transport system will move the freight into the cities where the majority of congestion occurs.

The purpose of this research is to develop a new decision-mechanism process for evaluating and comparing future modes of freight transport into urban areas. This will be accomplished by applying a new theory that current intermodal concerns, experienced at large port authorities around the nation, should be used as evaluation criteria for future modal options. The theory will be tested by combining the results of intermodal data collected from surveys, with alternative modes of future freight transport, into an evaluation matrix that compares and scores each option.

The following steps were taken to develop the evaluation matrix mythology:

- Perform literature review of proposed freight shuttle system on the Trans Texas Corridor
- Research potential future modes of freight transport into cities;
- Determine by a state-of-the-art survey, what intermodal procedures large seaports are utilizing to effectively distribute and transport freight containers into urban areas;
- Assess the technology, concerns and future ideas expressed by intermodal managers at the various port authorities;
- Apply survey responses from port authorities to the future Trans Texas Corridor freight system; and
- Develop a matrix of criteria to evaluate future modal options for urban freight transport;

To test the new evaluation method developed in the matrix, the I-35 corridor in Texas was used as a sample evaluation. The results revealed several useful comparisons of alternative options for future modes of urban freight movements. From the generated matrix data, it becomes very clear what criteria each modal option addresses and by how much. The sample evaluation performed was limited, since cost and public support criteria was not able to be included due to research limitations. However, the method demonstrated in this evaluation matrix, particularly the establishment of current intermodal freight data as evaluation criteria, should prove useful for future analysis.

While the purpose of the created matrix is not necessarily to recommend the best option, its primary objective is to provide a new, innovative approach of comparing transport options and weigh the advantages and disadvantages of each. Future studies by engineers, planners and politicians, should find this method of evaluating future modes of freight transport useful. There are also several other large-scale freight systems being planned or implemented around the country in California, New York, Illinois, and other countries around the world where this research may be of great benefit.

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INTRODUCTION

As the new millennium begins, a key challenge facing society is increasing traffic congestion. The primary problem commonly overlooked is not just a booming population, but it's the increasing freight demands, which is a direct result of a new era of international trade (1). TTI researchers estimate traffic congestion due to international freight traffic in Texas total \$800 million per year in physical and social costs (2). The primary cause of the problem, especially in Texas, is that there is simply not enough capacity on the highways to handle traffic, and the problem is expected to get much worse. By 2025, vehicle miles traveled in Texas is expected to increase by 83.7 percent (3). Sooner or later, a new innovative, long-term solution to the capacity problems must be undertaken. Just as the sea-ship revolutionized America in the 18th century, the railroad the 19th century, and the automobile in the 20th century, something will revolutionize the 21st century.

The future Trans Texas Corridor plan is one option for a new frontier in transportation engineering for the 21st century. It outlines a new vision for transportation in Texas, similar to the first proposals for the federal interstate highway system, in that it connects all major metropolitan clusters with a highway system that has a new 1200 feet right-of-way. The primary difference from the interstate system however, is that the new corridor does not enter cities, rather, it goes around them. The intention is reduce traffic as much as possible within cities and their metropolitan areas, since this is where 90 percent of the state population growth is projected to occur over the next 20 years (3).

One major piece of this new corridor is the separation of freight from passenger traffic by constructing a new, state-of-the-art freight shuttle system. Its purpose is to advance Texas freight on a new multi-use, statewide transportation network that improves the quality of life by (2):

- Reducing traffic congestion;
- Providing a safer, faster, more reliable mode for freight travel;
- Improving air quality, and noise; and
- Creating a transportation system to support economic growth;

While the freight shuttle system on the Trans Texas Corridor has been proposed to move freight between cities, it remains undetermined how to move freight into the cities. Several options for new modes of transport currently exist that can help relieve the increasing volumes of heavy truck traffic from urban highways. While some of these new options may not yet exist in the United States, they deserve careful evaluation.

The Problem in Texas

The booming trade generated by the North American Free Trade Agreement (NAFTA) has choked the Texas transportation network with freight (4). According to a 2001 FHWA report, Texas transports \$42.6 billion in international trade volume per year, more than any other state in the U.S (4). The impact on the Texas highway system in physical and social costs is over \$800 million annually. In addition, highway accidents involving heavy vehicles result in about 4,000 fatalities per year in the United States, and railroad accidents cause about 1,000 fatalities each year (5).

Texas is therefore in dire need of a long term solution. Texas Governor Rick Perry recently responded, "a recurring theme is that we cannot continue to address mobility and congestion in the ways of the past because congestion and need are expanding faster than traditional response methods can provide solutions"(6). In the past, Texas has traditionally responded by widening existing highways to increase capacity, such as the \$1.7 Billion Katy Freeway Project in Houston. However, not only is adding a lane of highway estimated to cost \$10 - \$20 million per mile, but urban areas in Texas no longer have the space to accommodate the addition of more lanes (6). Therefore, the search for new modes of freight transport that do require use of the public highway system is a vital option for the future.

If a freight shuttle system were implemented within the Trans Texas Corridor, passenger vehicles could be separated from freight vehicles between cities. However it remains undetermined how to transport this freight into cities and their urban areas. Therefore what is needed is a new method of evaluating future transport options that deals strictly with containerized freight movements into densely populated areas.

Research Objectives

The primary purpose of this research is to outline a new method of evaluating future modes of transport for container freight moving off the Trans Texas Corridor and into the urban areas. The new method of evaluation will be accomplished by determining current intermodal procedures and concerns experienced by large international port authorities around the nation. The objectives for developing this research are as follows:

- Perform literature review of proposed freight shuttle system on the Trans Texas Corridor;
- Research potential future modes of freight transport into cities;
- Determine what intermodal procedures large seaports are utilizing to effectively distribute and transport freight containers into urban areas;
- Assess the technology, concerns and future ideas expressed by intermodal managers at various port authorities;
- Apply responses from port authorities to the Trans Texas Corridor future freight system;
- Develop a matrix of criteria to evaluate and compare future modal options for urban freight transport off the Trans Texas Corridor; and
- Perform a sample evaluation of the matrix to the I-35 corridor in Texas;

Scope of Research

The scope of this research is limited to the transportation of containerized freight from the future Trans Texas Corridor to the major metropolitan areas. Due to time constraints, only the 15 largest port authorities in the United States were surveyed, in addition to the port authority in Rotterdam, Netherlands and Brisbane, Australia. Also, a sample evaluation will be performed on the I-35 corridor in Texas that stretches from the city of Laredo to Dallas.

THE PROPOSED FREIGHT SHUTTLE SYSTEM

The proposed freight shuttle system on the future Trans Texas Corridor, is a class of unmanned systems that transports capsules of container freight between terminals. The transport vehicle for the shuttle is powered by linear induction motors that run on steel rails in a tube 6½ - 8 feet in diameter (1). The idea is to transport capsules of freight containers in a concealed system that does not required travel on a roadway surface (2). The shuttle system will be operated within the Trans Texas Corridor right-of-way and will operate both above ground and below ground where necessary, separate from automobile traffic (2). The primary start up line will is proposed to be built along the I-35 corridor from Laredo to Dallas, since it handles the most freight volumes, as discussed previously in this report (2).

The primary purpose of the proposed freight shuttle system in Texas is to provide the separation of freight transportation from people movement. This separation will improve the efficiency and safety of both freight and public transportation in Texas (1). It helps the public sector by reducing the number of trucks on the highways mixed with passenger traffic. The reduction of trucks would also be more fuel efficient for the environment, and reduce highway maintenance costs, since highways are designed based on the average truck traffic. The benefit to the private sector would be increased travel time, container security, and potentially cheaper shipping costs (2).

Functions

The adoption of NAFTA has resulted in increased levels of trade between the United States, Mexico, and Canada (4). In particular, Texas serves as the primary gateway between Mexico and the U.S. Currently, the busiest and most congested corridor of freight movements for trucks is along the I-35 corridor from Laredo to Dallas, and the traffic is expected to worsen with infrastructure continuing to deteriorate. The proposed freight pipeline will serve as an alternative freight transport system to trucks, with the following characteristics (1,2):

- 450 miles of non-stop travel (Initial start up line from Laredo to Dallas);
- An automated, driver-less system;
- 24 hour service;
- Operation at high speeds (>45 mph);
- High capacity substitute for trucking
- Capability to transport 100,000 to 200,000 lb. per day;
- Environmentally sound;
- Power source supply of 161MW per terminal for two operating terminals;
- Provide pipeline structure both above and below ground (5-35 ft), depending on the terrain;
- Transport intermodal containers 20 or 40 foot equivalents; and
- Marginal cost of operation <\$0.10 per ton-mile (highly competitive);

Products Distributed

Currently, the proposed freight pipeline system is expected to transport containerized freight in the size of 20 or 40 feet equivalents (2). Containers are boxes made of aluminum, steel or fiberglass that can be handled interchangeably among trucks, railcars, barges and ocean vessels (8). The types of products within these containers are expected to include (4):

- Manufactured goods;
- Food and food products;
- Machinery;
- Electrical Equipment;
- Primary metal products;
- Primary non-metal products;
- Petroleum Products;
- Chemicals excluding fertilizers;
- Wood, lumber products; and
- Sand, gravel, shells, clay, salt, and slag;

Benefits

The expansion of the trucking and passenger vehicle volumes has led to the deterioration of Texas highways. The proposed freight shuttle system seeks to provide Texas with an alternative means to move traffic off the highway in an innovative manner. In addition to the relief of traffic volumes, the advantages this system provides are as anticipated to be as follows (2):

- Reduced damage to roadways and bridges;
- Improved freight-transport costs;
- System reliability;
- Energy efficiency;
- Improved delivery times;
- All-weather, 24 hour service;

- Enhanced cargo security;
- Reduced air and noise pollution;
- Low maintenance costs;
- More effective land-use; and
- Reduced petroleum consumption;

It should also be noted that one of the goals of the proposed freight shuttle system on the Trans Texas Corridor is not necessarily the reduction of the trucking industry. Like all other current freight modes, it would have the option to utilize this system to transport their shipments (2).

OPTIONS FOR TRANSPORTING FREIGHT INTO A CITY

Given that future Trans Texas Corridor (i.e. from Laredo to Dallas) will transport extremely high volumes of freight, it is currently undetermined how to move freight efficiently off the Trans Texas Corridor and into the city. Several options are available for transporting containers into the cities and their urbanized areas. The options can be categorized as either “conventional” or “unconventional” modes of transport. The “conventional” options refer to modes of transport commonly used today in Texas. There are also “unconventional” options which refer to modes that are either not very common or may not yet be utilized anywhere in the world.

Conventional

The conventional modes of freight transport in Texas are as follows:

- Truck;
- Railroad; and
- Intermodal;

Truck

Freight hauled by truck is the most common mode of transport, especially in Texas where 68.2 percent of all shipments are made by truck (4). This mode refers to both private truck and for-hire trucks. Based on the literature search, the author compiled several advantages and disadvantages of the current trucking industry in Table 1.

Also, it should be noted that costs to add a lane of urban freeway is between \$10 million - \$20 million per mile (5). This cost is usually not incurred by the trucking industry but rather by public transportation funding, unlike other modes of current freight transport.

Table 1. Truck Advantages and Disadvantages

Advantages	Disadvantages
• Accessibility • Door to Door Service • Cost (cheapest over short distances) • Availability • Political Support • Flexibility	• Long Distance Shipments • Contribute to Traffic Congestion • Air Pollution • Not 24 hour service • Highly Susceptible to major accidents with passenger traffic • Dependant on Oil, Gasoline

Railroad

Before the rise of the trucking industry in the 1960s and 1970s, Railroad was the most common mode of transport. In Texas, although the rail infrastructure is declining, still accounts for 6.7 percent of all shipments by value and 14.8 percent of all shipments by weight (4). The most common products currently moved by rail are chemicals, and coal products (4). Currently, this mode is usually only preferred over trucks when the distance of travel required is at least 500 miles (9). Advantages and disadvantages of railroad transport within cities is listed in Table 2. The information in Table 2 was gathered from the literature search performed by the author.

Table 2. Railroad Advantages and Disadvantages

Advantages	Disadvantages
• Cost (cheapest over long distances) • Faster (only over distances >500 miles) • Low Pollution • Relatively Safer from Public • Relieve Highway Congestion	• Short Distance Shipments • No Door-Door Service • Difficult to Access • Not always dependable • Difficult to track shipments

Intermodal

The intermodal mode is the transport of freight containers by various, interchangeable modes (10). Currently, this usually means a combination of rail and truck for delivery. On the national scale, intermodal is the primary mode of freight transport for Port Authorities (11). In coordinating the transport of freight from the Trans Texas Corridor freight system to the urban distribution centers, intermodal techniques and procedures will have to be applied, thus the reasoning of investigating intermodal procedures of port authorities in this report.

Unconventional / New Technology

Uncommon, yet innovative means of freight transport are as follows:

- Tube Freight;
- MagLev;
- Tubular Rail; and
- Rolling Highway;

Tube Freight

Tube freight is an unmanned system of close-fitting capsules carrying freight through tubes between terminals, powered by linear induction motors (1). It is essentially the same concept as the freight pipeline system mentioned in this report except that it is strictly underground, traveling below highway right-of-way into the city. Underground locations would be useful in environmentally sensitive areas where surface congestion makes surface right-of-way difficult or expensive to obtain (7). Since new transportation routes are expected to be difficult to obtain, major emphasis is presently being placed on intelligent transportation systems (ITS) that will more efficiently use the present highway system. Use of subsurface tube freight transportation in highly congested areas would allow ITS to operate more efficiently by removing high volumes of truck traffic carrying freight (1). Infrastructure for a tube freight

system could potentially be built underneath right-of-way of the current highway system. Advantages and disadvantages of a tube freight system are listed in Table 3 (1)

Table 3. Tube Freight Advantages

Advantages	Disadvantages
• Low operating cost • Automated Control • Weather-Proof • Low Pollution • Public Safety • High volume capacity • Relieves Highway Congestion	• High Capital Cost • Untested in commercial market • Potentially Difficult to Gain Support • Requires Years to construct and plan • Environmental impacts of construction • High Excavation Costs

Tube freight systems have been developed and built in Japan and Russia, however their systems are designed to move bulk materials rather than containers. The most notable underground freight system was the 50-mile electric railway system built under the city of Chicago for the collection and distribution of general cargo and coal, operating from 1904 to 1958, phasing out with the rise of the trucking industry (5). The city of Tokyo, Japan is currently proposing a tube transportation system that would perform the same function as the Chicago system, except that the Tokyo system would be automated and would interface primarily with trucks (1).

Maglev

Maglev technology is a freight and passenger magnetic levitation system concept based on superconducting magnets that propel vehicles along a guide way. AC current powers the magnets, allowing safe, cost-efficient, and high speed operation up to 350 mph (11).

Currently, there is an existing Mag-Lev system in Lathen, Germany (the German Transrapid) and in Shanghai, China (5). Several other systems are being proposed in China, Germany, Florida, California, and Maryland. The National Aeronautics and Space Administration "New Millennium Transportation System" proposes two national maglev systems in the United States. The first, a surface system, is not a tube system. The second, a "hypervelocity" system, would be an underground system operating in evacuated tunnels at speeds up to 6,400 km/h (4,000 mi/h) (1).

While the advantages for such a system are its high speeds and relatively noise-free travel, its primary disadvantage is cost. The estimated costs are between \$40 million - \$60 million per mile. However, adding a lane of highway is around \$10 - \$20 million per mile and a mile of railroad track is \$5 million (5). Although current MagLev systems only transport people, the author believes consideration should be given to MagLev as a freight transport system as well.

Tubular Rail

Tubular Rail is a new concept designed by Robert Pulliam (12). It is the opposite of other rail systems in that the rail is located on the transport vehicle and the wheels remain stationary on a concrete, hoop-like-structure. It travels "upside down" in a sense that the rail rides on top of the wheels. Its strengths are its high speeds (up to 300 mph), its elevated separation from land, high environmental quality (electrically

powered), and its futuristic style. The two primary weaknesses however, are that it is untested, and requires lots of infrastructure for the hoops (12).



Figure 1. Tubular Rail in Urban Areas

Concrete hoop structures are currently designed to be placed every 200 feet, creating a potentially high infrastructure requirement, especially if this concept were designed to handle freight. However, the Federal Railroad Administration is currently considering further developing the Tubular Rail concept into a scaled model for testing and research (12).

Rolling Highway

The Rolling Highway system is currently being utilized in Switzerland (13). It transports semi-trailers, along with their driver, onto actual train systems. It basically allows conventional trucks to drive up to the intermodal-rail facility and park on the train, for a small fee. The train then travels to its destination while transporting the trucks with it, as if it were normal cargo. The driver can then remain in the truck or move to another part of the train while the truck is being moved by the train. The system in Switzerland can carry up to 44 tones, and reduces traffic congestion while minimizing risks related to poor weather, congested roads and border delays (13).



Figure 2. Rolling Highway in Switzerland

There is also a similar system currently operating in Baltimore, Maryland. The only primary difference is that only the trailer itself is loaded onto the railcar, not the cab and driver (*11*).

SURVEY OF INTERMODAL FACILITIES AT SEAPORTS

A survey of urban intermodal distribution procedures was sent to intermodal managers at the 15 largest seaports in the United States (*10*). Of the fifteen, nine complete responses were received plus one additional response from the Port of Brisbane in Australia. A sample of the survey sent is in Appendix A.

Survey Development

The purpose of the survey was to gather information about existing and future intermodal technologies being used to distribute freight at major seaports. It was then determined how they can apply to the proposed freight pipeline on the Trans Texas Corridor, which could essentially lead to answers for transport into the city's urban areas. The following information was gathered by the survey:

- Modes of Intermodal Transport into adjacent urban area;
- Current freight distribution technology;
- Current Distribution Procedures being in use;
- Strengths and weaknesses of procedures and technology;
- Concerns related to Intermodal procedures; and
- Ideas for future technologies or procedures;

Survey Results

Summaries, assessments, and comparisons of the survey results are listed in the tables of this section. The results of the survey data and lit-reviews were collected and compared to identify common relationships among the port authorities.

Based on the findings of these comparisons, this research will suggest which procedures can apply to the Trans Texas Corridor. Information regarding the proposed future technologies for freight transport in Texas and the data collected from the Ports are compiled to analyze what procedures could work most efficiently. Also, data based on the concerns and future ideas of intermodal freight movements are analyzed as possible evaluation criteria for future modes of freight transport into urban areas.

Modes of Intermodal Transport

The data listed in Table 4 and Table 5 are important because the percentages of modal split indicated how much the port authorities actually experience "intermodal" transportation for urban freight movement. Therefore, higher percentages of rail and barge indicate stronger intermodal usage by the port authority. The average modal split data for all the ports who responded to the survey is provided in Table 4.

Table 4. Freight transported to adjacent urban area

Modal Split	Truck	Rail	Barge
Average	81.4%	17.9%	0.7%

For the Trans Texas Corridor, this means that no matter what mode of transport is chosen for urban transport, there will always be a portion of freight moved by truck. 81.4% is too large to expect to reduce to zero, but it would certainly be realistic to significantly reduce this number in the future.

Segregation of Urban-bound freight

The results of the survey show that 50 percent of the Ports currently have procedures to separate urban-bound freight from freight traveling greater distances beyond the nearest city. However, when combined with the modal split data collected from questions 1 and 3 (appendix A), the data shows that the all the ports with at least 15% rail into the urban areas are the same ports that separate their urban-bound freight. The combined data, listed in Table 5, is important because it suggests that segregation of freight will be required on the Trans Texas Corridor if there is more than one type of mode for freight transport in the urban area. The correlation from the data in Table 5 to the Trans Texas Corridor, is that the more “intermodal” a freight facility is, the greater the need for freight segregation

Table 5. Freight Segregation

Port Authority	% Rail	Segregation of Urban Freight
Baltimore (MD)	0	No
Brisbane (QLD)	0	No
Charleston (SC)	23	Yes
Houston (TX)	6	No
Jacksonville (FL)	40	Yes
Long Beach (CA)	25	Yes
Miami (FL)	0	No
New York/New Jersey	15	Yes
Seattle (WA)	70	Yes
Virginia	0	No

Assuming that the freight on the Trans Texas Corridor will be segregated, the next question then is, "how should the freight be segregated?" Table 6, lists the responses received from survey regarding how freight is segregated.

Table 6. Segregation Explanations

% of Ports	Who Separates the freight?	Explanation
80%	Private Stevedores	3 rd party individuals who are <i>not</i> employed by the Port or Trucking industries
20%	Terminal Operators	Employed by the Port Authority

From Table 6, it should also be noted that both options almost always occur at the port facility (14) It may therefore be necessary for the proposed Trans Texas Corridor freight shuttle system to provide the necessary infrastructure to segregate the urban-bound freight. Given this recommendation it also highly

likely that the segregation process could be automated, especially since the proposed transport mechanism on the Trans Texas Corridor will already be driverless (2). An automated segregation system would eliminate the need for a third party individual or freight broker, thereby reducing cost and time for shipments.

Types of Intermodal Distribution Technology

Listed in Table 7 are the types of intermodal technologies currently used by the ports responding from the survey. This information is important because it helps describe “how” the intermodal distribution of freight is carried out. The second column of the table indicates the percentage of Ports surveyed who currently use this technology. The definitions provided in Table 7 are from the Georgia Ports Authority (8):

Of these technologies that can be applied the Trans Texas Corridor system, maritime cranes and gantry cranes can be eliminated since they are used only near water. If the freight shuttle system is automated, forklifts can also be eliminated, since those require a driver. That leaves terminal chassis, conveyor belts, top-lifters as the equipment that would most likely be utilized by an automated, freight distribution system.

Table 7. Freight transported to adjacent urban area

Technology	at Ports	Definition
Maritime Cranes	90%	Cranes located in or near the sea
Gantry Cranes	90%	Track-mounted, shore side crane used to load/unload containers
Terminal Chassis	90%	Equipment designed to move containers by highway to/from terminals
Forklifts	70%	Drivable machines that lift and transport cargo between terminals
Conveyor Belts	30%	Automated belts that transport cargo
Straddle Carriers	20%	Motorized, rubber tire equipment that transports a row of containers
Reach Stackers	10%	
Top Lifters	10%	Like a forklift except it lifts from above rather than below
MafiTrailors	10%	
Rail Flat Cars	10%	
TransTainers	10%	Crane that straddles 4 railway tracks for loading containers on rail cars

Intermodal Distribution Procedures

All distribution procedures that the Port Authorities listed on the survey were relatively all similar to each other. Figure 4 shows an illustrated summary of the procedures, as developed by the author. The procedures reported by the majority of Ports in simple terms are as follows:

1. Containers are discharged from the ship using gantry and maritime cranes
2. Containers are placed on yard chassis, container stack or stevedore/terminal yard using straddle carriers, hustler, etc.
3. Clearances are obtained (customs, ship-line)
4. Custom Broker (3rd party individual) sends delivery order to Port
5. Port sends container to intermodal terminal or rail yard
6. Trucks or Railroad pick-up container at location

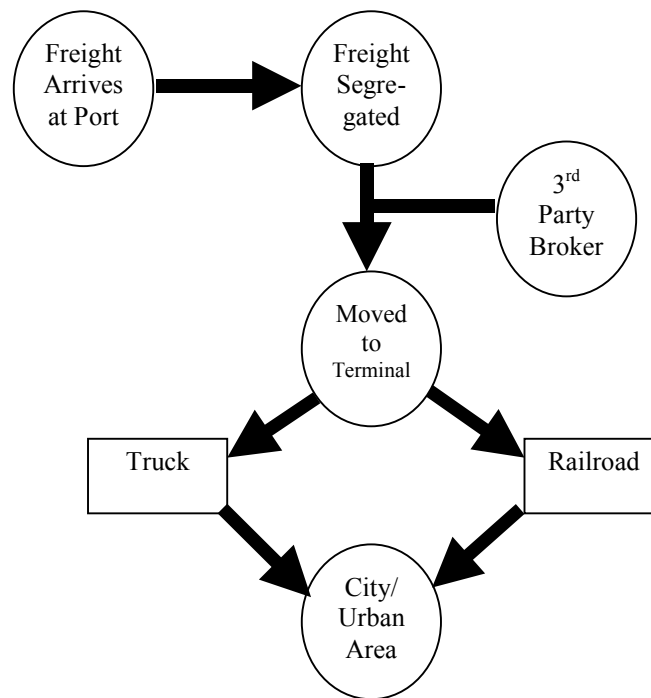


Figure 3. Summary of Intermodal Distribution Process

Concerns and Opportunities for Improvement

Concerns and opportunities for improvement reported by the intermodal managers are listed in Table 8.

Table 8. Intermodal Concerns

Frequency	Concerns / Opportunity for Improvement
40%	Rail infrastructure
50%	Expansion of terminal capacity
20%	Avoid dense populated areas
40%	Inadequate road infrastructure
20%	Warehouses need 24-hour operation
30%	Cargo information flow
30%	Public-private partnerships
30%	More efficient procedures

Table 9. Foreseeable Future Technologies

Frequency	Future Technologies
40%	Increased Rail Transport
30%	New mode of transport
30%	Automation / Robotics
10%	GPS / e-processing
10%	24-hour service
10%	Alternative fuels

Interestingly, the proposed freight shuttle system on the Trans Texas Corridor, in its current planned design phase, will address all of these concerns. The catch then is to find a mode of transport into the city that can also address all of these concerns. The matrix in following section will attempt to provide a new method to do just that.

EVALUATION MATRIX FOR FUTURE TRANSPORT OPTIONS

A matrix is developed by the author that provides a method for evaluating the transportation options into the city for containerized freight. The evaluation criteria are based on current intermodal concerns and foreseeable future technology data collected from intermodal managers in Tables 8 and 9. The purpose of this matrix is not necessarily to recommend the best option, but rather to provide a new, innovative approach of comparing transport options and weigh the advantages and disadvantages of each. As a stretch, a sample evaluation of the I-35 corridor in Texas was performed with results listed in Figure 4.

Matrix Procedures

The software utilized for creating the matrix was Trans-Dec 2.0 (Transportation Decision Analysis Software). The software, which was originally developed by the Texas Transportation Institute and Ken Opiela, is a powerful analysis tool that uses basic mathematical algorithms to weigh and compare several options (15). The procedures utilized by the author to create this matrix for evaluating future modes of freight transport into cities were as follows:

1. Define the goal
2. Enter evaluation objectives
3. Assign weight to each objective
4. Select scale for each option

Define the Goal

The goal in this case is to evaluate modes of transport for containerized freight into cities and urban areas.

Enter Evaluation Objectives

The author recommends that evaluation objectives should be based on current intermodal concerns and foreseeable future technologies, as listed in Tables 8 and 9 of this paper. Although costs and public

support of each option was not included in this research due to time constraints, it should be included as evaluation criteria in future, professional evaluations.

Assign Weights to Each Objective

The author recommends that the weight of each criterion should be based on the severity of each current intermodal concern. In this paper, severity was based on the frequency of responses for each concern.

Select Scale for Each Option

There are several ways to scale each option. The user of the matrix can basically create whatever scale system is desired. Due to time limitations, the scale for each option in Table 9 was simplified to be either “yes” or “no”. A response of “yes” to each objective was assigned 10 points, and a response of “no” received zero points. These were ratings were only assigned to each of the first 6 objectives, which represent intermodal concerns, from Table 8. In order to emphasize the significance of intermodal concerns over future ideas, the remaining four criteria in Table 10, which are based on data from Table 9, received a score of 8 for “yes” and “2” for no. Points were received for because the author believes that just because an option does not meet a future technology (i.e. alternative fuels), it is not as bad as not meeting one of the concerns (i.e. avoid dense populations).

It should also be noted that fourth objective listed in Table 10, “increase efficiency”, utilizes a scale of “none”, “fair” and “excellent”, with each receiving a score of 0, 5, and 10 respectively. This was only used to demonstrate that binary rating scale of yes or no is not the only option available to future users of the matrix.

Sample Evaluation for I-35 Corridor

For an example of how the recommended procedures can apply, the intermodal data gathered from port authorities was combined with four alternative modes freight transport, in order to test the matrix evaluation process on the I-35 corridor in Texas (i.e. from Laredo to Dallas). The inputted data for the matrix is listed in Table 10. The four modes of transport listed are those researched previously in this paper, and are merely examples of what can be tested. The evaluation criteria, listed at the top of the table, were based on intermodal data gathered in Table 8 and Table 9.

It should be emphasized that there are at least two limitations to the sample evaluation provided. Most importantly, cost was not included as evaluation criteria. For any real, professional analysis undertaken, cost is always included in modal comparisons (9). Due to time constraints, this example did not include a cost analysis. Another major criterion that was not included was how much public support each option would have. Public support is also vital for modal comparisons because it measures the potential public approval of the mode.

The author recommends that in addition to the intermodal criteria included in the evaluation matrix in Figure 4, cost and public support should also be included for a more accurate comparison. Cost data could be entered for construction, system maintenance, and basic operations. Public support data could be entered in terms of environmental impacts on air and noise pollution in addition to measuring the public perception of each idea by means of a survey or vote. Investor potential could also be included by including data for project bonds, rates of return, net present values and other economic measures.

If cost and public support data could be included in future analysis, the matrix tool developed would then provide a more accurate comparison for evaluating future modes of freight transport.

Table 10. Evaluation Matrix

	Increase Infrastructure Capacity	Increase Terminal Capacity	Avoid Dense Population	Increase Efficiency	24 hour Operation	Cargo Information Flow	New Transport Mode	More Rail Transport	Automation	Alternative Fuels
Weight	20	15	10	10	10	10	5	5	5	5
Scale	0/10	0/10	0/10	0/5/10	0/10	0/10	2/8	2/8	2/8	2/8
Tube Freight	Yes	No	Yes	Excel	Yes	Yes	Yes	No	Yes	Yes
MagLev	No	No	No	Excel	Yes	Yes	Yes	Yes	Yes	Yes
Tubular Rail	No	No	No	Fair	Yes	Yes	Yes	No	Yes	Yes
Rolling Highway	Yes	No	Yes	Fair	Yes	No	Yes	Yes	No	No

DISCUSSION

The results of the I-35 corridor sample evaluation in Figure 4 have revealed several useful comparisons for evaluating future urban freight movements. From the generated chart, based on the matrix data, it becomes very clear what concerns each modal option addresses. Although the tubular rail concept was ranked the highest in Figure 4, it is not necessarily the recommended mode of transport, primarily because cost and public support criteria were not able to be included in the evaluation matrix. However, the method demonstrated in this evaluation matrix, particularly the establishment of current intermodal data as evaluation criteria, should prove useful for future analysis.

The ranking chart in Figure 4 clearly demonstrates how much each mode of transport addresses each criterion. The legend to the left of the chart in Figure 4, lists all the criteria from the matrix in Table 10. Depending on how high the weight is assigned to each criterion in Table 10, the graph shades in a larger box for each criterion, as color coded by the legend. If a criteria is not met for a modal option, the colored boxes may either not be present or may appear much smaller. By utilizing this process, the matrix evaluation procedure is able to sum up a total score for each option, depending on how well it met each criterion.

Future studies by engineers, planners and politicians, should find this method of evaluating future modes of transport for containerized freight into cities useful. It clearly exemplifies how each mode of transport addresses intermodal concerns.

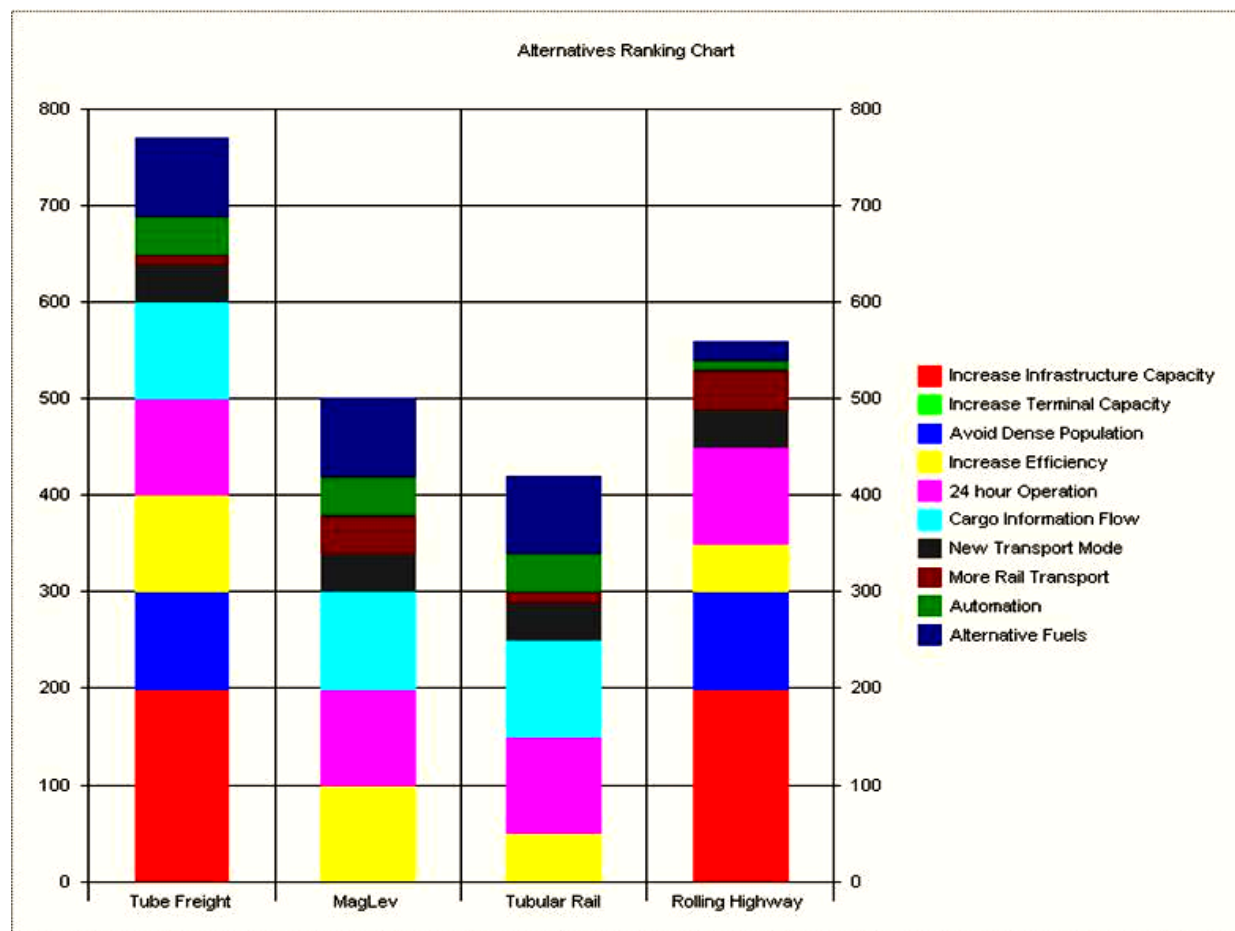


Figure 4. Matrix Results

RECOMMENDATIONS

It is recommended that future research should be continued for applying uses of the evaluation matrix researched in this report. Additional research on assessing the cost and public support for modal transport options would be very beneficial. Also, methods of obtaining future funding for future freight transport projects, such as public-private partnerships, would also be very applicable research for new solutions to traffic congestion in the 21st century.

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- Joe Bryant, Intermodal Manager, Port of Jacksonville
- Charlie Jenkins, Operations Manager, Port of Houston

- Steve Roop, Research Scientist, Texas Transportation Institute
- Richard Schiefelban, Research Scientist, University of Texas
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- Dave Thomas, Intermodal Manager, Port of Charleston
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APPENDIX A - INTERMODAL TRANSPORTATION SURVEY

By: Chad Zorn, Graduate Assistant Researcher
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Texas A&M University

Please take a few short minutes to fill out this very brief survey, containing only 7 questions. Your response will be very beneficial to the future of freight transportation technologies and improvements. **Please return this survey by email to (c-zorn@ttimail.tamu.edu) or fax (979-862-2708) no later than July 11, 2003**

The results of this research will be collected in a compendium – Papers on Advanced Surface Transportation Systems, 2003 (published by the Southwest Region University Transportation Center). Your response will be greatly appreciated. A copy of the compendium can be obtained for free if you request.

Please note that the following questions refer primarily to “container” freight:

- 1) What types of Intermodal Transport are being utilized to move freight between the port and into the adjacent urban area? (Please estimate % by mode)
 - a) %TRUCK:
 - b) %Railroad:
 - c) %Other (please describe):

- 2) In general, what types of freight distribution technology is currently being utilized at your Port to transport the freight?

Maritime cranes ____ Gantry Cranes ____

Terminal chassis ____ Forklifts ____ Conveyor Belts ____

Other (please specify) ____

- 3) Is the freight that is going into the adjacent urban area being segregated (in any way) from the freight that is traveling greater distances beyond the nearest city?

No ____ Yes ____

If Yes, how?

- 4) In brief, please list all of the steps in getting the container freight from the ship to its final destination in the adjacent urban area.
- 5) What are the two greatest strengths and two greatest opportunities for improvements in your freight handling process?
- 6) Are there any current or future concerns related to your Port's intermodal distribution procedures?
- 7) There are several ideas about future technologies and procedures that may eventually be used. In 20 years, do you foresee any major changes or technological advances? Do you believe more freight should be transported by rail (or some other form) into the adjacent urban area rather than by truck?

CHAD ZORN

Chad Zorn is from Houston, Texas and came to Texas A&M in the fall of 1999. He received his Bachelor of Science degree in Civil Engineering in May of 2003, with a specialty in Transportation. Chad has worked for various transportation engineering companies, including transportation design work with Epsilon Engineering, a summer with Parsons Brinckerhoff in Brisbane Australia, a summer with PB in Herndon, Virginia, and one month with PB in Houston on the Katy Freeway Project. Prior to work with PB, Chad worked two summers with Tejas Surveying in Sugar Land and one summer with the Texas Department of Transportation in Houston.

While at Texas A&M, Chad served as President of the American Society of Civil Engineers in 2002, member of Chi Epsilon, and served as the Traffic Count Coordinator chair for the student chapter Institute of Transportation Engineers. Chad also completed the Public Policy Internship program in 2001 and the Eisenhower Leadership development program in 2002.

DEVELOPING A MODEL RESPONSE PLAN FOR FREEWAY INCIDENTS

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SUMMARY

The unpredictable timing and nature of incidents makes them difficult to manage. An incident not only reduces capacity in the direction of the incident, but can also have significant impact on traffic in the opposing lane due to rubbernecking. Incident Management involves the detection and verification of an incident, the actual response, clearing and recovery to full capacity of the freeway. An efficient well-organized incident management program will help reduce the adverse effects of freeway incidents.

Optimum response is sending the right equipment and personnel to the incident scene quickly. Response times vary from region to region with institutional, safety and funding issues the main concerns. Significant gains due to reduction of the response time can be achieved through the adoption of sound incident management police and easy, less-costly options.

To examine the response process in the incident management plan, existing literature sources were reviewed and current state-of-the-art practices sampled through a survey of transportation agencies. Consideration of low-cost as well as efficient options was examined with the corresponding merits and demerits. As a result of the research, a step-by-step procedure to develop a model response plan, which may be used to improve the response times to freeway incidents. Certain options for reducing response times were also identified as part of this plan.

It is recommended that due to the continuing evolvement of traffic characteristics and hence incident occurrence, the incident response process needs continual tracking for optimum performance. Careful consideration of a region's particular needs must be done before selection of any particular option for reducing response times. In addition, it is also recommended that the state DOTs take the recently published FHWA's Traffic Incident Management Self-Assessment Guide, to assess the whole incident management plan, and find ways of improving it.

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INTRODUCTION

An incident is defined as any non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand. Such events include traffic crashes, disabled vehicles, spilled cargo, highway maintenance and reconstruction projects, and special non-emergency events (e.g., ball games, concerts, or any other event that significantly affects roadway operations)(1).

Incident management involves the detection and verification of an incident, the actual response, clearing, and recovery to full capacity of the freeway. A big part of reducing the total time from the detection of an incident to the recovery of the incident is in how quickly the response team (police, fire, emergency medical services, etc.) arrives on the scene. In incidents that involve injuries, reducing response times becomes most critical.

A cross-cutting survey of incident management plans in the United States, reveals a varying range in response times of various State Departments of Transportation (DOTs) (2). Reducing the response time can save lives and mitigate the impact of an incident on traffic. Much can be done in sharing the knowledge attained by successful DOTs in this area of incident management to help eliminate this difference. One factor that may inhibit ability to improve dramatically on one's response time is availability of funds. Thus it may be prudent to look at ways of helping improve the response to freeway incidents using some other less sophisticated but effective ways to help smaller state DOTs on smaller budgets, maintain an appreciable level of response time for freeway incidents.

Research Objectives

A list of research objectives for the paper is listed below. These were to:

- Identify the state-of-the-practice in freeway incident response;
- Analyze the strengths and weaknesses of current response strategies;
- Identify ways of improving the process of responding to various incidents;
- Develop a model response plan; and
- Validate the model response plan.

Scope

The scope of the report is on the response aspect of the incident management process, i.e., the time after an incident is verified until the time an appropriate response arrives on the scene of the incident and clearance begins. The report is also limited to incidents occurring on freeways.

Report Organization

The report is divided into sections to allow for easy reading and maneuvering through. There are seven sections in this report. The first section is an introduction to the report, which outlines the research objectives and defines the scope of the research. The study methodology section includes information on how the research was performed, with an explanation on the literature review, data collection methods and the analysis of results obtained. The literature overview of the report is in the section under "Incident Management: An Overview", where various literature sources are used to provide a brief historical evolution of incident management with a focus on the response aspect and the current or state-of-the-practice in the various states.

The results of a survey sent out to eight agency contacts are presented in the section under survey responses. General practices in incident response are outlined in this section as given by the agency contacts. An analysis of these results is given in the next section with a discussion on the various issues to overcome in developing an ideal response plan. A set of performance criteria are used to analyze these

various responses and these are discussed also. The developed response plan is provided in the sixth section. To validate this plan, an expert panel had an opportunity to critique the response plan and their comments are documented in the seventh section. A findings section and a recommendation section on some of the critical issues not covered in the main report and areas that should be further improved or looked at, round up the report.

STUDY METHODOLOGY

Literature Review

A literature review was performed to identify the trend in incident management over the years. A review of current practices was also done with a focus on the role of incident response in the whole incident management process.

Data Collection

The data collection task of the research consisted of a survey of seven transportation agencies to determine the current practices and have an idea of current trends in conducting responses to freeway incidents. The survey was conducted by means of a survey questionnaire shown in Appendix A. The individuals contacted had a direct connection with the operation of incident management on freeways. The agency officials were asked a series of questions that were used to identify among other things, the agency policy on incident management, cooperation of various agencies in incident response, and general performance of the incident response teams.

Data Analysis

This task in the project contains a summary of survey responses obtained. Strong points of surveyed incident response plans were adopted and improved methods identified for certain weak aspects of these response procedures.

Development of Model Response Plan

From the analysis of the survey results and the literature review performed, a model response plan was developed. This plan will incorporate all aspects of response procedures not identified in the agency responses but which may be important in any response plan. Alternatives were developed with a consideration of funding as easy, simple to implement, and less costly methods were suggested. It was intended that the model response plan developed be an initial step to developing a final model response plan.

Validation of Response Plan

After the development of this plan, an expert panel had an opportunity to review this response plan and make suggestions and comments as to its effectiveness and usefulness. This panel consisted of four individuals considered experts in the area of incident management were contacted for this purpose. Their review of the response plan provided the validation for the plan and ensured the usefulness and applicability of the plan to today's agencies in their everyday response to freeway incidents.

INCIDENT MANAGEMENT: AN OVERVIEW

What is Incident Management?

Incident management as noted earlier, is defined as the systematic, planned, and coordinated use of human, institutional, mechanical and technical resources to reduce the duration and impact of incidents, and improve the safety of motorists, crash victims, and incident responders. It can also be defined as the process of managing multi-agency, multi-jurisdictional responses to highway traffic disruptions. It involves five main steps or a variation of these steps: incident detection, incident verification, incident response, site management and incident clearance and recovery (1). These stages do not occur sequentially and Figure 1 shows a timeline for the various steps of the incident management process.

Incident Detection

Incident detection is the process by which an incident is brought to the attention of the agency or agencies responsible for maintaining traffic flow and safe operations on the facility. Methods commonly used to detect and verify incidents include mobile telephone calls from motorists, closed circuit television cameras (CCTVs) viewed by operators, automatic vehicle identification combined with detection software, electronic traffic measuring devices (e.g. video imaging, loop or radar detectors) and algorithms that detect traffic abnormalities, motorist aid telephones or call boxes, police patrols, aerial surveillance, department of transportation or public works crews reporting via two-way radio and roaming service patrols.(1)

Incident Verification

Incident verification entails confirming that an incident has occurred, determining its exact location, and obtaining as many relevant details about the incident as possible. Verification includes gathering enough information to initiate the proper initial response. Incident verification is usually completed with the arrival of the first responders on the scene. However when hazardous materials are involved, the verification process may be quite lengthy. Methods of incident verification include the following: CCTVs viewed by operators, dispatch field units (e.g., police or service patrols) to the incident site, communications with aircraft operated by the police, the media, or an information service provider and combining information from multiple cellular phone calls (1).

Incident Response:

Incident response includes dispatching the appropriate personnel and equipment, and activating the appropriate communication links and motorist information media as soon as there is reasonable certainty that an incident is present. Effective response mainly involves preparedness by a number of agencies (i.e. planned cooperatively) for a variety of incident types, so that response to individual incidents is coordinated, efficient, and effective (1,2).

Site Management

Site management is the process of effectively coordinating and managing on-scene resources. Ensuring the safety of response personnel, incident victims, and other motorists is the foremost objective of incident site management. Site management encompasses the following activities: accurately assessing incidents, properly establishing priorities, notifying and coordinating with the appropriate agencies and organizations, using effective liaisons with other responders and maintaining clear communications (1).

Incidence Clearance and Recovery

Incident clearance is the process of removing wreckage, debris, or any other element that disrupts the normal flow of traffic, or forces lane closures, and restoring the roadway capacity to its pre-incident condition. At times, this may also include temporary or permanent repair to the infrastructure (1). The goal is to recover quickly from the incident and return the freeway to its operating capacity.

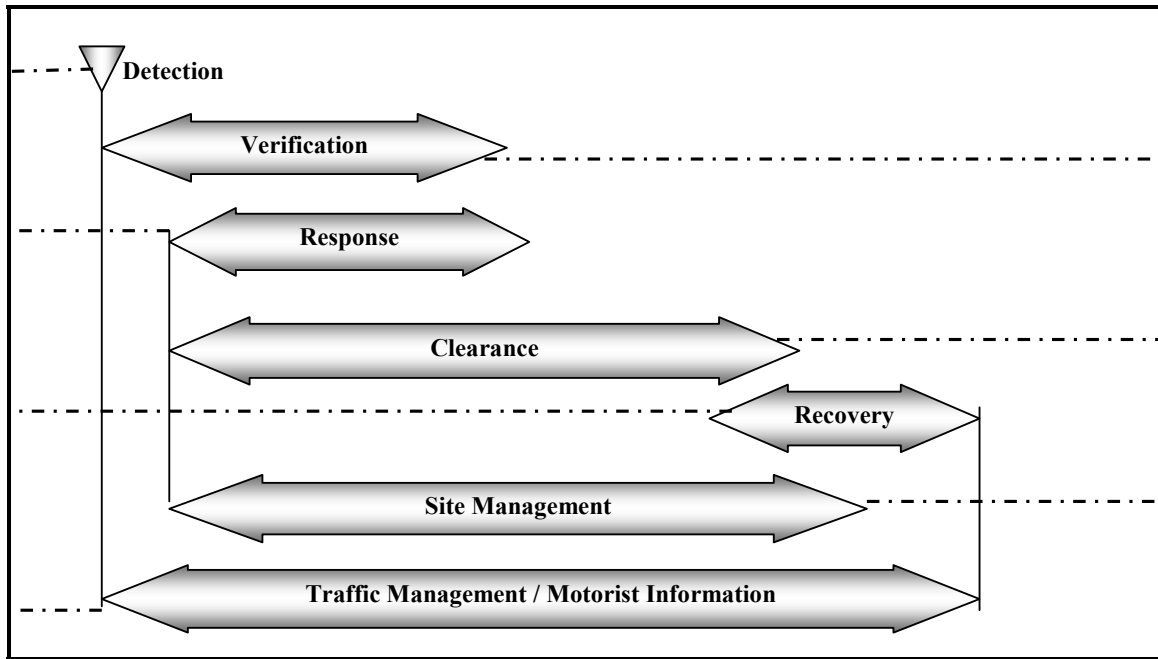


Figure 1. Timeline of Stages in the Traffic Incident Management Process (3)

The Evolution of Incident Management

Pioneering Research

It is estimated that over half of the traffic congestion in the U.S. is caused by incidents (4). Incidents such as accidents construction and maintenance activities, adverse weather condition, parades, sporting events, tourist attractions, or other events can cause congestion by temporarily increasing demand or reducing the capacity of the transportation network. The subject of incident mitigation includes a host of options and technologies for dealing with incidents, ranging from accident prevention and education to preplanned hazardous materials cleanup. Most of these mitigation measures for dealing with incidents, which include vehicle accidents, breakdowns, and so on, date back to the early 1960s. (5)

One of the useful early incident management options reviews to deal with incident management options is a highly detailed and comprehensive six volume review and evaluation of low-cost incident management options in the late seventies -Urbanek and Owen in 1977 (6), Urbanek and Rogers in1978 (7), and Urbanek and Colpitts in1978 (8). The emphasis in these works was on low cost options. Urbanek et al. did a demonstration project in Tampa Florida, and showed how low cost incident management could improve traffic operations on a heavily traveled bridge. They found that emergency vehicle access and stationery tow truck surveillance/response reduced response times by half (8).

Early Incident Management Plans

Detroit provided an example of the early use of these surveillance and control systems, courtesy patrols, ramp metering, and highway advisory radio (9). As early as 1960, the John C. Lodge Freeway System in Detroit, included a surveillance and control system, courtesy patrols, ramp metering, highway advisory radio, variable message signs, a traffic surveillance center, and closed circuit television monitoring (10). Since the early systems, many technologies have been refined to include new incident detection algorithms, highway corridor simulation models, and improvements in video (closed circuit television, CCTV) technologies (5).

Chicago's Incident Management Program began in 1960 with the opening of the Kennedy Expressway. To combat the congestion, the Illinois DOT assigned 20 people in pick-up trucks to patrol the Expressway during the morning and evening peak periods. This patrol was eventually named the "Minuteman Patrol". (11,12,13,14)

During the mid-1970s service patrols were operated in Los Angeles as part of a major traffic management research project (15). In this project, units were operated in both ways-posted awaiting dispatch when an incident is detected, and patrolling assigned beats looking for incidents, while at the same time being available for dispatch, yielding good results and considerably cutting the time to clear the freeways with the roving service the better of the two methods.

It has been reported that incident response teams have been used with considerable success since the 1980s (5), and by 1991, incident management programs existed in nearly 30 cities, and several other cities around the country were developing these programs to minimize the impact of incidents (16).

An evaluation by Roper of the Los Angeles area freeway management system indicated that a 10:1 benefit/cost ratio could be realized by using freeway incident response teams. Tow truck courtesy patrols were used successfully for rapid removal of disabled vehicles, particularly on point facilities such as bridges (17). Urbanek and Rogers used incident response time, capacity reduction and assumed queuing with a constant demand in their evaluation of the potential benefits of tow trucks, and the trucks proved quite favorable (7). As an example, Roper noted that in 1985, the Illinois Department of Transportation's 35 tow trucks were involved in over 100,000 assists (17).

Components of Incident Response - Who is Involved?

A survey of successful incident management practices across the United States, listed the following agencies as part of the incident response process (2):

- State and local transportation agencies (including state departments of transportation and highway agencies that operate and maintain the road network in the region);
- State and local law enforcement agencies – includes state, county, and city police departments that are responsible for public safety and enforcement;
- Fire and rescue agencies – include county and city fire, ambulance, and support response agencies; these also include volunteer and private fire and rescue organizations;
- HAZMAT clean-up services – include private companies that provide cleanup services for HAZMAT incidents; fire departments have HAZMAT containment capability, but rely upon private companies for HAZMAT cleanup;
- Towing and recovery companies – include private companies that provide towing and recovery services for highway incidents; and
- Public and private traveler information providers – include public agencies and private companies that collect, process, and disseminate traffic and transport-related information to benefit travelers using methods such as commercial and cable television, radio, internet, and changeable message signs.

All these agencies have crucial roles in ensuring incidents on freeways are responded to promptly with minimal losses or consequences to the traveling public.

Successful Incident Response Programs in the United States

There have been considerable successes chalked up by Incident Response systems in many cities across the United States, and a few examples are presented below (2):

- The Maryland CHART program reported a benefit to cost ratio of 5.6 : 1 and benefits amounted to 2 million vehicle-hours of non-recurrent congestion delay savings;
- The Georgia DOT's NaviGator system reported reduced the average time to generate an automated incident response after incident verification from 9.5 minutes to 4.7 minutes during the first three weeks of system operation. Benefit to cost ratio in 1997 of 2.3:1 (calculated as a result of reduced delay due to accidents on the freeway);
- In Houston, Texas, the TranStar System reported annual delay savings of 572,095 vehicle-hours with an economic value of \$8.4 million, and reduced incident detection and response times cut hydrocarbon emissions by 91kg/day;
- In Philadelphia, the I-95 Traffic and Incident Management System (TIMS) contributed to the reduction of freeway incidents by 40 percent, freeway closure time cut by up to 55 percent, incident severity rate reduced by 8%;
- In Brooklyn, New York, the Gowanus Expressway/Prospect Expressway Rehabilitation Incident Detection System reduced average time to clear incidents by 66% from 90 to 31 minutes;
- In Minnesota, the Minnesota Highway Helper Program helped reduce duration of vehicle stalls by 8 minutes;
- In San Antonio, Texas, total accidents reduced by 35% and average response time reduced by 20%, benefits translate to annual savings of \$1.65 million; and
- In San Francisco, California, the Freeway Service Patrol which started in August 1992 had assisted more than 90,000 drivers as at January 1997 and hydrocarbon emissions reduced by 32 kg/day.

The Marks of a Good Incident Response Plan

Every good traffic incident response plan needs to be constantly evaluated. After review of various sources of literature (1, 2, 3, 4, 6, 14), key aspects of any good incident response process were identified as a means of measuring any incident response process. These were grouped into four main transportation areas namely: institutional, safety, efficiency, and user related.

Institutional

Almost all literature sources agree on one thing: that the inter-agency communication and coordination is crucial to any incident response process (1, 2, 4, 18, 19, 20). A standard set of inter-agency response action plans, tailored for various scenarios and supported by shared data, will improve the speed of the incident response process. Greater inter-agency coordination, increased incident management awareness, and technological advancements have resulted in significant improvements to the efficiency of incident response (2).

Inter-agency personnel training programs, shared information and more coordinated response procedures are other fruits that result from a strong institutional base. Another critical mark of any good response plan is the good communication between responders from different agencies (2).

Safety

The safety of emergency responders as well as motorists is an important criterion to consider in evaluating any incident response process. A good response procedure seeks to minimize the exposure of

the responders to secondary accidents during response as well as on site management accidents (2,8). This can be enhanced through training and field inspections with participating agencies having representatives present to communicate any rules and regulations governing response teams. Training must stress driving regulations or policies of the department, as well as teaching defensive driving rules. A documented material needs to be developed to outline these regulations and any personnel not adhering to safety rules should face punitive measures.

Efficiency

If incident management is to warrant the huge investments being poured into the sector today then it is proper to demand a certain amount of promptness and timelines to the level of response to freeway incidents. This quality is important especially as it gives a positive image on the public's perception of state DOTs.

User Related

Another measure of a good incident response process is the perception of the general public to the activities of the responders. Service providers have over the years earned good ratings with the public for the timeliness of their assistance, the feeling of safety and security derived from uniformed personnel assistance and free services provided.

The acceptance and approval of the public in an incident response plan is crucial for the cooperation and participation of citizens in the incident process and eventual sustaining and improvement of the response process. Citizen cards have been used in Florida to obtain feedback from the public as to the performance of the SunGuide service patrols.

SURVEY RESULTS

In order to confirm, and have an idea of current trends in conducting responses to freeway incidents, a state Department of Transportation (DOT) survey was conducted. The agency's past experiences with successful and unsuccessful incident management programs was a factor in the selection process. Agencies surveyed included DOTs in California, Florida, Georgia, Maryland, Minnesota, Missouri, North Carolina and Texas – San Antonio District.

California Department of Transportation – San Diego

Incident Response Process

After identification and verification of an incident by technology based field elements, or staff, the traffic management team (TMT) member is dispatched along with the California Highway Patrol (CHP). Others may be requested on site after field verification. Having an active list of responsible personnel and contact info has worked well. Sometimes jurisdictional issues develop that adversely affects the team approach. ITS plays a key role in Caltrans's operations, as cameras allow for quick identification and verification of incidents, and the subsequent dispatching of TMT personnel for timely assistance.

Service Patrols

Caltrans operates the TMT, which serves as service patrols together with the California Highway Patrol. Responding to incidents is the top priority for TMT, and their ability to respond in a timely manner is crucial. Caltrans however, does not have a manual for response but draft guidelines for TMT (response team) operations have been developed.

Average response time for the incident responders (TMTs) is 15 minutes and is mainly dependent on the location of the incident. At certain times during the day, or during major events, the service patrols are dispatched to rove areas that are prone to traffic conflicts. This option allows incidents to be detected quickly and responded to promptly.

Funding

Budget allocation to Incident Management is approximately \$ 1,500,000 per fiscal year, with all going into responding to incidents on freeways. These are federal and state funds.

Inter-agency Coordination

Inter-agency coordination helps greatly in response time reduction because it affords early and often cordial communication in preparation for various incidents that could happen on the highways. With the increase in the development of technology, and better inter-agency coordination, Caltran's ability to respond more quickly to incidents would vastly improve (21). The means of communication among response teams include mobile radios, cellular phones and pagers.

Florida Department of Transportation (FDOT) - Miami

Incident Response Process

The incident management process starts with the control center being notified by a participating agency or citizen. Personnel in the control center may also detect an incident using ITS devices such as CCTVs. Upon incident notification/detection, the SunGuide Interim Operations Center (IOC) then does the following sequentially:

- Uses ITS devices (cameras and signs);
- Dispatches Service Patrols; and
- Advises SmartRoutes (an Advanced Traveler Information Services partner) for display of incidents on the Web, 511 phone service, and e-mail alerts. (22)

Even though ITS technology plays an important role in incident management in general, currently ITS devices do not cover all state freeways. Cameras are used for quick and reliable incident verification/management. Signs are used to warn travelers about incidents, website, 511 phone service, and e-mail alerts are also used to warn travelers about incidents. The service patrols or response teams are sent armed with all the available information needed to resolve the incident in a timely and efficient manner. (22)

Service Patrols

According to the respondent from FDOT, the service patrols are an effective tool for the FDOT, and they are popular with the motoring public (22). Figure 2 shows a SunGuide service patrol responding to a disabled vehicle. The average response time for Service Patrols stands at approximately 10 minutes, although there are no precise performance measures at this time. This response time depends on the type of incident. Other factors affecting the way response tasks are conducted include the weather, severity of incident and the volume of traffic. The Florida DOT is currently working on a draft incident response manual for its service patrol, but has a manual on incident management.



Figure 2. Florida DOT SunGuide Service Patrol Responding to an Accident

Funding

Budget allocation for Miami's Incident Management program stands at \$4,762,813 out of an operations and maintenance budget of \$5,909,683.00. State and federal funds provide this. Approximately 80.59 percent of this goes specifically into the area of response.

Inter-agency Coordination

Inter-agency coordination is an important factor in incident response for the FDOT and the key roles of each agency are identified so that a pre-planned approach to incident response is developed. Thorough training among agencies is an important means of improving inter-agency coordination and rapport, which leads to the eventual improvement of the freeway incident response (22).

Georgia Department of Transportation (GaDOT) - Atlanta

Incident Response Process

Georgia DOT's incident management unit is called the Highway Emergency Response Operators (HERO) Unit (23). An incident can be detected in a number of ways: a HERO Operator patrolling their route; a motorist call in; a 911 center call requesting assistance; or through one of the operators at the TMC monitoring surveillance cameras. Once an incident is detected and verified, a HERO is dispatched, if one is available, and if the incident is on one of the GaDOT's designated routes. If not, the appropriate local jurisdiction's police, fire, EMS, and/or wrecker service is called as needed (24). TMC operators provide the HEROs with information on the number of vehicles involved in an incident, the exact location and the potential for injuries. They can also provide visual confirmation of the traffic conditions at and approaching the incident scene. Information about the incident is placed on Changeable Message Signs to warn motorists of the condition so they can make informed decisions about changing their route. This information is also made available to callers to the NaviGator Traffic Information Telephone Line, and is on the NaviGator web site. (24)

The HEROs and TMC HERO dispatchers communicate with SouthernLinc radios. In general, the GaDOT does not have the ability to communicate with disparate agencies (24). This often makes

coordination at an incident scene very difficult. There are also several SouthernLinc dead spots in the area that make communication difficult. The Georgia State Patrol also uses SouthernLinc, so HEROs usually communicate with them at an incident scene pretty well. But because most of the incidents in the Metro Atlanta region are handled by the local jurisdiction where they occur, and because this equates to dozens of different agencies, communication during an incident is often a problem (24).

Service Patrols

According to the respondent from GaDOT, the HERO program works very well, and is one of the most popular programs the GaDOT has. The only complaint concerning the HEROs is that there are not enough of them. HEROs operate 24 hours a day on the weekdays, and a 10 hour shift on the weekends, but they are always on call to respond to major incidents, even those that occur off their normal route. There are currently about 52 employees in the Unit, and 13 designated routes throughout the Metro Atlanta region. HEROs are highly trained in emergency medical response and first aid. HEROs receive a minimum of 350 hours of overall training before they are qualified for incident response and management patrol (25). Figure 3 shows a HERO truck en route to an incident scene.



Figure 3. A HERO Response Vehicle En Route to an Incident Scene (25)

The GaDOT is in the process of writing specifications for an automated location and dispatch system that will be very useful in response time. This system will involve GPS tracking on the vehicles, and a mobile data terminal from which two-way communication is possible, and data can be entered, eliminating the need for many of the radio transmissions and paper log entries they now have to do. (24)

The GaDOT recently completed an update of the HERO standard operating procedures, and also has a Regional Incident Management Manual that was recently updated. The purpose of the former document is to provide a singular standard written source of Department Standard Operating Procedures, which promote the effective and efficient operation of the HERO unit. The HERO Unit's Standard Operating Procedures Manual contains written standardized procedures. This manual is utilized by the HERO UNIT personnel as the official reference and guide for the daily operations of this unit (26). In Figure 4 above, details of a shoulder assist procedure for HERO personnel from the Standard Operating Procedures Manual, is shown.

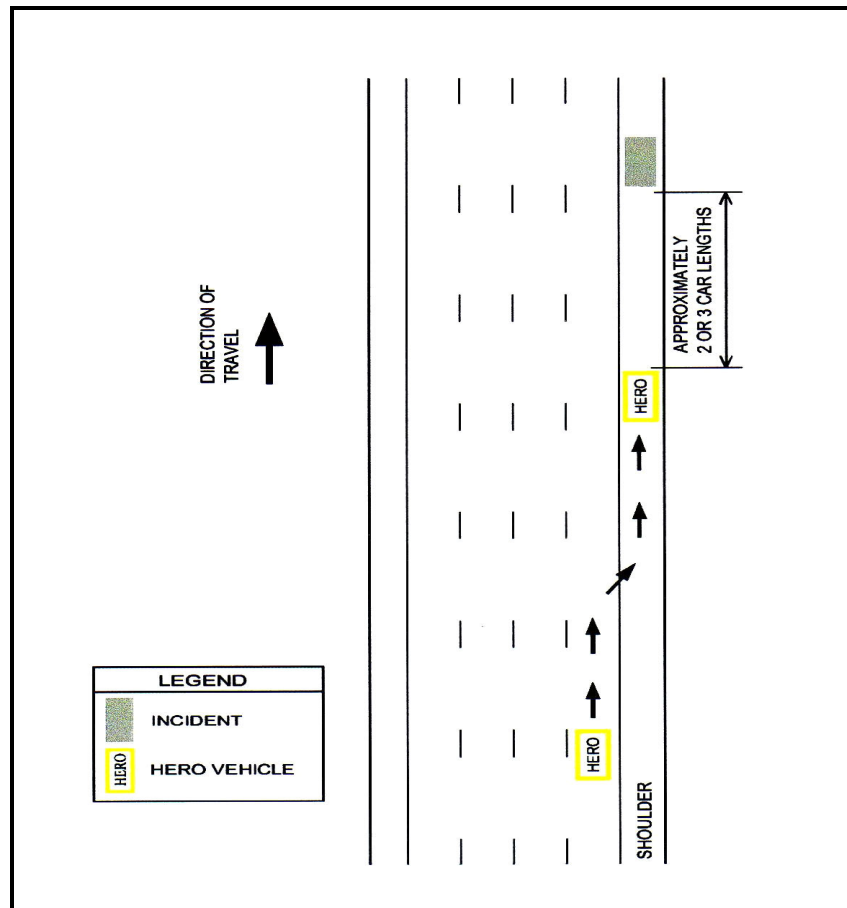


Figure 4. Shoulder Assist of HERO Operator (26)

The department of transportation is beginning to track response times, both within the HERO program and among agencies involved in the Incident Management Program. They are in the process of establishing HERO and regional response and clearance time goals. The average response time for the HERO Unit is approximately nine to ten minutes, and the current goal is to get it under nine minutes. This is an average across all incidents worked by the HERO Unit, and includes motorist assists, debris removal, and crashes. (24)

In general, response time is more critical when a stall or crash blocks a travel lane, due to the increased risk of secondary crashes. In such incidents, the HERO operators will rush to this scene with lights and sirens going, whereas an incident on the right shoulder will be responded to as quickly as possible without the use of lights and sirens. Anything blocking a lane is of the utmost importance since the risk of secondary crashes is high in these incidents. If they are responding to an incident in the travel lane, they turn on lights and sirens and drive on the emergency shoulder if possible. This is only done in emergency situations since this can be hazardous (24).

The availability of HERO's and the availability of enough trucks operational at any given time can affect the response times. And if a major incident occurs, and several HEROs have to respond, the response to other lesser incidents may have to be delayed, or turned over to local authorities to handle (24). The number of lanes on a multi-lane highway may affect the HERO's ability to handle the incident on his own. When a crash or stall is blocking middle or inside lanes of a multi-lane section, the back up of another HERO may be required to move it to the right shoulder. Added response time for the second or

maybe even multiple HEROs to come for assistance would increase the overall response time as well as the time to clear the incident.

Funding

The HERO Unit operates on a federally funded budget of \$2.9 million per year, but a request has been made to increase the budget to \$4.5 million per year. The increased budget is needed due to an increased coverage area and the high costs of maintaining and replacing the HERO vehicles. The entire HERO budget is used for incident management, and to support response to incidents. There is also a \$6.5 million budget for the operation of the NaviGator ITS. Some of this supports the operation of the TMC, which also plays a role in quicker incident detection and response (24).

Inter-agency Coordination

The GaDOT currently has a demonstration project to exchange information electronically between their system and the City of Atlanta's 911 center. This is a model project demonstrating center-to-center data-sharing using CORBA (Common Object Request Broker Architecture) technology. When completed, and if successful, that should play a large part in reducing response times, as the information would be automatically available and shared among all agencies that need it, eliminating or at least reducing the need to rely solely on telephone calls (24).

The GaDOT realizes that institutional issues pose the biggest hurdles (24). Each jurisdiction and each agency have their own way of doing things their own priorities. In order to improve incident management in the metro Atlanta region, and get all agencies on the same page and working together, the GaDOT has formed the Metro Atlanta Traffic Incident Management Enhancement (TIME) Task Force. This has gone a long way in improving incident management in the region.

Maryland State Highway Association (SHA) - Baltimore

Incident Response Process

Maryland State Highway Administration (SHA) works in partnership with the Maryland State Police. When the police become aware of an incident, either through their patrols or through citizen calls, they inform the SHA. Likewise, when the SHA, through the Coordinated Highway Action Response Team (CHART) traffic monitoring system, becomes aware of an incident, they notify the state police. CHART is responsible for dispatching the SHA traffic patrol vehicles to incidents. These vehicles are equipped to provide motorist assistance, support traffic management and remove debris from accidents scenes. (27)

CHART uses over 60 cameras, over 70 traffic speed detectors as well as patrol vehicles and cellular calls from citizens to collect information on incidents. This information includes: location, queue length, lanes impacted, number of vehicles involved, types of vehicles involved, hazardous materials, injuries, weather conditions, etc. This information allows CHART to develop an appropriate response plan. CHART uses communication between operations center and field units, to share this information about the incident, so that responders can more quickly arrive at the location of the incident and are better prepared for conditions at the scene (27).

Service Patrols

CHART emergency response vehicles patrol the metropolitan freeways in Washington and Baltimore from 6 AM to 9 PM weekdays. These are mainly service-oriented patrols and Figure 5 below shows a CHART operator assisting a motorist whose vehicle has stalled. The SHA has a well-detailed incident response manual - The CHART Standard Operating Procedures Manual (28). The Statewide Operations Center (SOC) will contact the nearest patrol, via a statewide radio system owned and operated by the

SHA, and direct them to the incident scene. CHART also has the ability to communicate with other agencies, including local governments, fire & rescue, 911 dispatch centers, and the Department of Natural Resource among others, by fax, e-mail, pager and cellular phone, in order to ensure that all responding agencies have complete information. CHART patrol units use State Highway owned two-way radios and Nextel two-way, cellular phone service for field communications (27).



Figure 5. CHART Operator Assists Motorist

Response time is one of the fundamental evaluation factors for CHART and is reported to senior managers through a process called Managing for Results (MFR), which emphasizes measurable key performance areas (KPA's). As a result, finding ways to improve response time is a high priority in CHART.

In the year 2002, CHART's average response time was 28 minutes. In more involved incidents, there are more resources that need to arrive at the incident scene. Therefore, while the initial response time may be comparable between incidents, response time for all necessary resources may vary depending on the complexity of the incident. Responding to incidents on bridges pose a problem for the CHART responders as the limited shoulder space inhibits the ability to reach the incident and stage response vehicles. Incidents that occur in proximity to freeway access ramps and crossovers are also a challenge (27).

Figure 6 gives a summary of response times for various TMCs in the CHART program, for 2000 and 2001 (28). The response time is defined as the arrival time minus the time incident report was received. Only data with response times greater than 60 seconds and less than one hour were considered.

Funding

The annual CHART budget averages \$ 10 million in capital and \$ 6.8 million in operations yearly. Of this about 25% of the capital budget and 50% of the operating budget are focused on incident management. Thus, about \$2.5 million for capital and \$3.4 million for operations are allocated to CHART incident management annually (27). However, since incident management is tied to all of the other activities of CHART, it is difficult to identify these funds separately, and therefore, these numbers are very rough estimates.

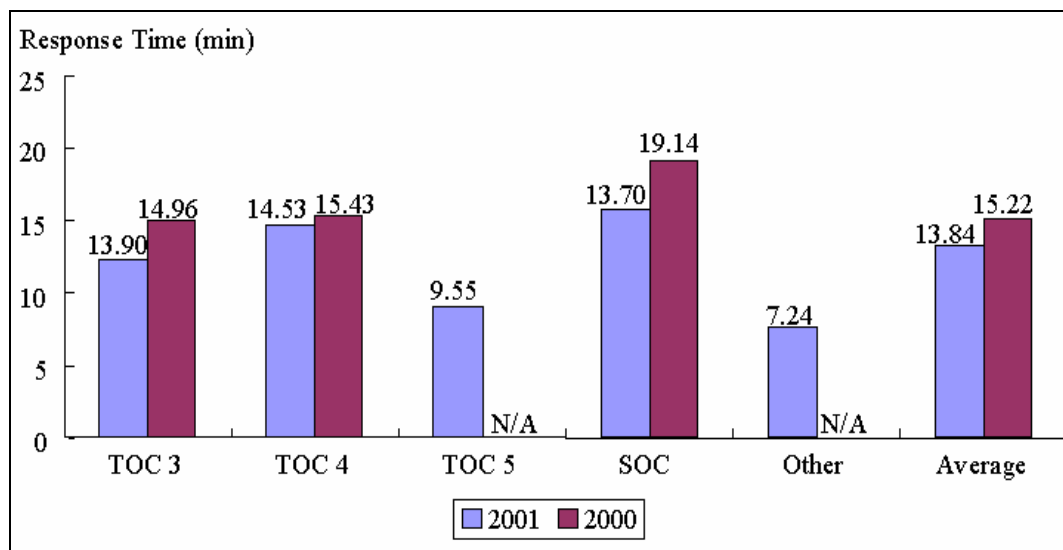


Figure 6. Response Times of CHART Traffic Management Centers for 2000 and 2001 (28)

Inter-agency Coordination

Inter-agency coordination and cooperation is the cornerstone of the CHART program. Each responding agency knows its roles and responsibilities, as well as what resources are available within their own organization as well as the other responding agencies. In addition, the Maryland State Highway Administration sponsors inter-agency training on a regular basis to assure that all responding agencies are aware of the importance and consequences of managing congestion (27).

Minnesota Department of Transportation (MnDOT) – Minneapolis – St. Paul

Incident Response Process

The general process for responding to incidents on freeways is outlined in Figure 7 for minor incidents (29). CCTVs help in initiating the whole process by verifying incident locations.

Service Patrols

The MnDOT operates freeway service patrols. These operate 24 hours on both weekdays and weekends. The state patrol dispatch, state patrol troopers, local police and fire departments, ambulances and towing companies as well as maintenance dispatch teams all operate on a 24-hour, seven-day schedule.

The MnDOT has the Traffic Incident Management Recommended Operational Guidelines document which outlines responsibilities for various agency response teams for different types of incidents on freeways (30). On the average, response time for state patrol dispatch is 10 minutes, which the department considers quite satisfactory (31). Staffing levels of state troopers, weather conditions such as snow and rain all increase response times. A summary of response times for state patrol dispatch and towing trucks are shown in Table 1. These results are in minutes and are for a time period of 5.30 am to 8.30 pm for seven days a week on a stretch of I-494 freeway (31).

Funding

Budget allocation for freeway service patrols is currently at one million dollars annually. Also two personnel are hired to assist with program development, control room operations, etc. at a cost of \$100,000 annually. Funds meant for construction have also been used for enhanced reference markers.

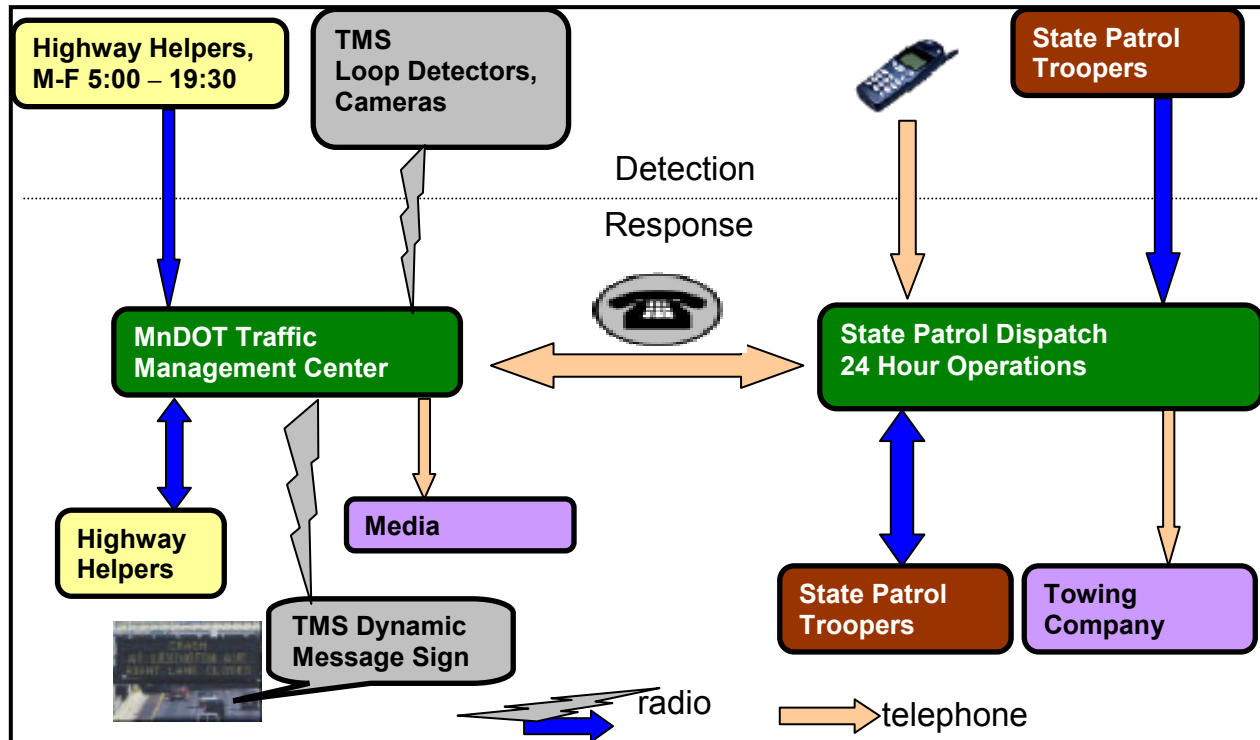


Figure 7. Minor Incident Informational Flowchart for MnDOT (29)

Inter-agency Coordination

MnDOT freeway service patrols use 800 MHz radio systems together with the state troopers, but overcoming the operational issues of who can communicate on which channel is most challenging. Getting law enforcement to make this a priority is challenging. The law enforcement agency is short staffed and often this issue does not get enough attention. However some level of coordination is achieved and this helps in quicker response to location verification and availability of responders improves. For example if a freeway service patrol can respond to a flat tire incident, the trooper can go to the crash (31).

Missouri Department of Transportation (MoDOT) – St. Louis

Incident Response Process

In the 1970s, Missouri had 11 different maintenance buildings. After an incident was detected, the response was rotated among the maintenance buildings and this led to long response times, sometimes in excess of an hour. The traffic operations section of the MoDOT took over from maintenance, and equipment was built specifically for this purpose including a traffic information center (TIC). The authorization to go into the maintenance building was granted. This resulted in calls coming directly to traffic operations in the TIC, which then sets response into motion. (32)

Table 1. Summary of Response Times for State Patrols and Towing Trucks in Minnesota (31)

	Tow Truck					State Patrol Trooper				
	Count	Avg. Resp. Time	Max	Min	Std. Dev.	Count	Avg. Resp. Time	Max.	Min.	Std. Dev.
Blocking Crashes*	21	23.7	49.7	5.9	12.5	41	9.6	33.5	0.6	8.3
Blocking Stalls **	9	38.6	118.2	1.2	40.0	10	13.1	29.0	1.2	9.0
All Crashes	56	31.4	96.5	0.4	19.7	137	11.9	74.6	0.2	10.4

*Just crashes

**Stall or unoccupied

State radio is the means of communication used internally. There is a move toward the use of Nextel communication between the TIC and service patrols. The MoDOT is in the process of adding a data link with a GPS system to all response trucks so that from the TIC, operators can see which responder vehicle is closest to the incident and have them respond by sending messages via text. This also facilitates the simultaneous documentation of response times. (32)

Service Patrols

In the year 2002, the MoDOT responded to 33,122 incidents on its freeways. The MoDOT in St. Louis, operates the freeway service patrol which is a Motorist Assist Program (MAP) operating from 5:00 am to 7:30 pm and an Emergency Response Crew (ERC) operating between 7:30 pm and 4:00 am. The MAP operates on 162 center lane miles in the metro area while the ERC handles maintenance related incidents not only in the Metro Area but district wide (32). Figure 8 shows an example of an MoDOT ERC tow truck.

There is an incident response manual currently being developed and records of all incidents reported and responded to, are kept by operators on the job in the TICs and by the responders as well. To reduce the incident response time, coded directions are given to responders to provide specificity. An example is LL #1, meaning first lane from left on a multi lane highway. Once a call is made it goes directly to the TIC and a corresponding call is made to any service patrol truck in the vicinity of the given area. It takes an average of ten minutes to get to the site of the incident after verification is done. Information is first given to response team as to the general direction of traffic, say West Bound 70 and I-94, and specifics are filtered through as time goes on (32).

The volume of traffic or congestion affects the response time. This is particularly so as vehicles used are not emergency vehicles and hence drive with traffic. Also, shoulders are only used if traffic speeds drop to less than 5 miles/hr and even then, only with a police escort. This is to ensure the protection of responders from people pulling onto shoulder. Typically, less response times have been reported during rush hour traffic and this is due to a heightened sense of duty on the part of responders and increased readiness.



Figure 8. A MoDOT Emergency Response Crew Tow Truck

Funding

Two million dollars in state and federal funds was the budget for the current year on the TIC including incident response and ITS efforts. A substantial portion of this goes into acquiring and maintaining trucks and equipment as well as hiring staff for the MAPs and ERCs (32).

Inter-agency Coordination

MoDOT has a generally smooth working relationship with other participating agencies in the incident management process. Jurisdiction is not a problem as the grounds have been well laid out to ensure smooth running of incidence response program. The MoDOT has formed a Traffic Management Team (TMT) with other participating agencies and jurisdictions including the Highway Patrol Service, fire service, EMSs, and tow truck companies. The incident management coordinator represents MoDOT in the TMT with the fire chief normally in charge of this team. Inter agency coordination helps reduce response times as well as the duration of the incident (32).

North Carolina Department of Transportation (NCDOT) - Raleigh

Incident Response Process

The law enforcement notifies the North Carolina DOT, and the DOT responds to the scene. Otherwise, CCTVs are utilized to identify and verify incidents before response.

Service Patrols

The North Carolina Department of Transportation (NCDOT) operates the Incident Management Assistance Patrols (IMAPs), which operate from Monday to Friday, 6am to 9pm. One runs 24 hours a day, 7 days a week in a remote area patrolling once every two hours. The patrol in Charlotte operates also on Saturday and Sunday between 6am and 9pm. To improve the safety of responders, the NCDOT provides defensive driving training for its IMAPs. However there is no record of accidents involving IMAPs. The NCDOT receives many complimentary letters of appreciation and good media coverage from time to time for their IMAP program (33).

The NCDOT has no manual for response teams, however tries to minimize response times. There is no documented average response time. Volume of traffic on freeway, configuration of freeway and availability of appropriate response teams all affect the response times to freeway incidents.

Funding

The Incident Management Assistance Patrol is funded at approximately three million dollars per year for 400 miles of coverage. There is a dedicated project in the state's Transportation Improvement Program that covers most of the costs. This is a federal aid fund with a state match (33).

Inter-agency Coordination

Getting law enforcement to truly believe that timely response and clearance is important is a challenge for the NCDOT. To solve this, there are periodic (usually quarterly) Inter-agency Incident Management Team meetings hosted by the NCDOT for agencies across the state. There are 30 teams in all and these are on the county level. The police service, fire service, towing companies, and media personnel are usually invited to these meetings. On the street, IMAPs coordinate directly with law enforcement in some areas and in other areas, the coordination is facilitated through the TMCs (33).

Texas Department of Transportation (TxDOT) - San Antonio

Incident Response Process

After the Automated TransGuide Solution Scenarios detects incidents, and courtesy patrols or police are dispatched to the scene. The incident scene is secured and support responders in the form of tow trucks, fire service or HAZMAT clean up teams, are brought to the scene. Traffic is diverted or managed upstream as appropriate (34). The Automated TransGuide Solution Scenario is an ITS program consisting of CCTVs and GPS systems that detect incidents as they occur on the freeways thus reducing detection and verification times considerably.

Service Patrols

The San Antonio district of TxDOT operates courtesy patrols, which are service patrols working 24 hours and 7 days of the week. The courtesy patrols are popular in San Antonio and receive by far the most positive response due to their assistance to the public. The response time varies greatly depending on the time of day, day of work and location. It takes the police within four minutes to get to the scene of an incident and takes between ten to fifteen minutes for the courtesy patrols to be on the scene on average.

Funding

The courtesy patrols are a state-funded program. In some communities for example in Dallas the Sheriff's department has taken up the task of funding the service patrols while in Houston, some automobile dealerships supply vehicles to the district DOT (34).

Inter-agency Coordination

There is a police dispatcher present at the TransGuide center in San Antonio. This ensures that the correct responders and appropriate numbers are dispatched within minutes of the incident. Also San Antonio police radios are usually used for communication between the various incident responders, as well as state radios and cell phones.

Summary of Agency Responses

DOT budgets ranged from \$1.1 million to \$4.8 million with most coming from federal and state funds. Agencies that typically were involved in incident response as noted in the survey responses include DOTs, police agencies, fire and rescue teams, public works, transit authorities, private agencies such as private towing agencies, and the media. Most of the DOTs operated freeway units and had or were in the process of developing incident response manuals. The main factor affecting response times of these units was the level of traffic volume on roadways. Response times ranged from 10 to 28 minutes. A summary of some aspects of the survey responses received from the state DOTs is presented in Table 2 following.

ISSUES INVOLVED IN THE DEVELOPMENT OF AN IDEAL RESPONSE PLAN

Agencies Cooperation and Coordination

Issues Involved

As far back as 1976, inter-agency cooperation was noted as the main problematic area of incident response (35). Urbanek et al. noted that although the intentions of the agency providing services were generally good, services rendered were often inadequate. Typically personnel at the higher levels of the highway departments (now departments of transportation) were not hesitant about becoming involved but had greater difficulty in fulfilling the requests that had been made. This could have been due to the lack of awareness of the severity of the problem or to lack of communication from the higher ranks to the lower levels (35).

Advances in communications technology have outpaced coordination efforts among responding agencies. Though greater inter-agency cooperation has been achieved there is still much that needs to be done (24). In a study of current state-of-the-practice of incident management, it was found that in most of the areas studied, incident response components from different agencies continue to be dispatched independently, and on-scene coordination is sporadic (2).

There is also the problem of who should be in charge of incident command. Some states have the fire chief as the incident commander by law, while in other states the police chief plays that role. A unified command structure is preferred else where, with command transfer to appropriate people throughout the team of responding agencies with specific knowledge in certain disciplines (36).

Solutions to Consider

To overcome this, it is important to bring all stakeholders in the incident management process to the table. The following tasks need to be performed in facilitating a better inter-agency cooperation and coordination:

- Form a TMT comprising all participating agencies and jurisdictions in the incident management process; (18,19)
- Recognize the importance of the part each agency plays is important and address the concerns of each participating agency and / or jurisdiction;
- Sign an agreement to ensure that resources of each participating agency or jurisdiction are made available to the incident response process;
- Develop trust for each agencies assessment of traffic incident situations through visits to each other's agency, and learn where facilities are stored as well as the length of time to assemble equipment for an incident response (36); and
- Organize interim programs including inter-agency training programs to facilitate good relations among personnel of participating agencies.

Table 2. Summary of Agency Responses - Response Process

	Texas – San Antonio	North Carolina	Missouri	Minnesota	Maryland	Georgia	Florida	California
Freeway units	Courtesy Patrols(CP), state patrol police (SP)	NCDOT Assistance Patrols,	Motorist Assist Program (MAP), Emergency Response Crew (ERC), State Patrol.	Freeway Service patrol, State Troopers	CHART Operators, MD State Police	HERO Units, state police.	Sunguide Service Patrols, Florida Highway Patrol	Traffic Management Team (TMT), California Highway Patrol (CHP)
Hours of operation	24/7	6am – 9 pm all days	MAP – 5.00 am to 7.30 pm; ERC: 7.30pm to 4.00am	24/7	6am – 9pm Weekdays	24/7	24/7	24/7
Average Response Time (RT)	SP: 4 min CP:10-15 min	Unknown	10 min	10 min for FSP; 12 min for State Troopers	28 min	10 min	10 min	15 min
Factors affecting RT	Time of day, day of week, location, traffic conditions, HAZMAT spill.	Traffic volumes, freeway configuration, staffing problems	Traffic volumes	Weather, staffing levels of state troopers.	Time of day, HAZMAT spills, proximity to access ramps, Bridges	Traffic volume	Weather, severity of incident, traffic volumes	Incident location,
Response manual	In the process	None exists	In the process	Yes	Yes	Yes	Draft	Draft guidelines for TMT
ITS applications	CCTV's, loop detectors, CMSs, ATIS	CCTV's, CMSs,	CCTV's, CMSs, emails	CCTV's, CMSs	CCTV's, loop detectors, CMSs, ATIS, cell phones, Cadd	CCTV's, video and loop detectors, CMSs, Cadd, ATIS	CCTV's, CMSs, ATIS, 511 phone service	CCTV's, CMSs,

Inter-agency Communication

Issues Involved

Communication between participating agencies in the incident response process is crucial. Most of the DOTs surveyed did not have a very good inter-agency communication procedure and this often makes coordination at an incident scene difficult. Communication during an incident is often a problem, because most of the incidents are handled by the local jurisdiction where they occur, and this involves dozens of different agencies (24). The challenge is the ability to deploy technology that will support center-to-center and mobile communications between agencies, throughout a statewide regional network (27).

Solutions to Consider

Advanced means of inter-agency communication and thus information sharing are on the horizon. The Georgia DOT currently has a demonstration project to exchange information electronically between their system and the City of Atlanta 911 Center. This is a model project demonstrating center-to-center data-sharing using CORBA (Common Object Request Broker Architecture) technology (24).

A less costly but probably less effective means of communication is by using compatible two-way radio equipment and common nomenclature or terminology. This would help provide better information to the respondent personnel as well as improve site management. However, this has proved a problem with the different jurisdictional barriers crossed in responding to freeway incidents.

Funding

Issues Involved

The primary source of funding of incident management has been federal and state funds. Funds need to be made available exclusively for incident management. A 24-hour operation of the TMC and incident response teams means that more personnel need to be hired to run the DOT service patrols, the TMC operations, State or County Highway Police Patrols etc., and these require additional sources of funds. Volunteers or service patrols funded by citizen groups must rely on private donations and their own personal savings to finance a dedicated freeway unit. Some basic equipment like first-aid kits and flares can be secured from local or state governments, but these may stretch the already tight state budgets.

Service patrol vehicles are another area where availability of funds is critical. These vehicles are driven under very harsh conditions, and as such they require a lot of maintenance and have to be replaced more frequently than most other DOT vehicles. They are also involved in crashes due to their having to work under moving traffic and on the roadside and hence funds will be required for repairs as well (24).

Solutions to Consider

There are no easy ways of finding innovative sources of funding. Funding for incident management is usually derived from a combination of local, state, and federal sources. However the current tight state and federal budgets require that some means of funding service patrols in particular be found. It is not advisable to rely primarily on federal funding for operational costs, since funding levels vary over time as well as the regulations governing their use (1). Donations from assisted motorists are one source of funding but not very reliable and in Georgia, gratuities to service patrol operators are prohibited (26). In some places, automobile dealers have struck deals with the DOTs to supply vehicles at lower rates, while in Maryland money from Congestion Mitigation and Air Quality (CMAQ) funds have been used. The area of funding is not an easy one and DOTs must constantly use their imagination to tap existing sources of financial support and uncover new ones (8).

24-Hour Operation

Issues Involved

For incident response to be effective and be credible, it may be necessary to operate on a 24-hour session. An incident that occurs immediately before the start of morning rush hour, for example, can cause serious congestion and delay if the TMC is not operating fully at such a time. Most transportation department employees have been accustomed to working the 9 am to 5 pm hours. Comprehensive incident management requires however, that coverage of freeways be made possible 24 hours a day and 7 days a week. This has facilitated the need for some employees to work shifts on weekends and outside the normal working hours.

Solutions to Consider

Operating a 24-hour schedule may not be easy to implement and requires an understanding of the need for incident management as well as a commitment of TMC employees to make this operational system happen. Enticement offers including overtime payment and days off during normal working hours as well as employee education need to be vigorously pursued to whip up the enthusiasm of DOT employees working these shifts. A proper analysis of benefits associated with a 24-hour operation (with consideration of incident distribution by time of day, day of week) as against the costs of such an operation needs to be done.

Jurisdictional Boundaries

Issues Involved

Jurisdictional issues surface when two or more agencies/organizations must respond to an incident but where their respective responsibilities are unclear, or if the immediate objectives of their field personnel conflict. Jurisdictional problem areas include definition of site responsibilities, field communications, legal ramifications, political sensitivity, perspectives of each agency, and administrative coordination among agencies (37).

In attempting to structure a more cooperative relationship between the police and DOTs, traditional operating procedures hamper progress. In some instances, police patrols cease to communicate with the TMCs once they get to the incident site. In other cases, there is a lack of trust in the assessment of different agencies of the incident situation or severity (36). This results in a lack of cooperation in sending of response teams to certain incident scenes. Another basis for the conflict lies in each agency's perception of its own responsibilities and those of its counterparts. Police officers often consider themselves in charge of freeway operations and a conscious effort needs to be made to identify the contributions of the DOTs to freeway operations (2).

Solutions to Consider

To counter this, responsibilities of the various agencies need to be spelled out clearly without ambiguity. Jurisdictional barriers can require legislation, or may be overcome through executive level review and discussion or by examining and adapting roles in cross-jurisdictional situations. Frequent communication between agencies needs to be pursued with site visits organized by agencies to visit each other and learn of the training procedures of each as well as being exposed to the difficulties each agency persons go through in performing their duties.

Table 3. Summary of Issues Involved in an Incident Response Process

Issue	Concerns	Solutions to Consider
Agency Cooperation and Coordination	• Problems with incident command • Poor field communications • Lack of trust in assessment of incidents by different agencies	• Formate TMT • Sign agreement for availability of resources and personnel • Develop trust through personnel training programs
Inter-agency Communication	• Communication among disparate agencies • Different jurisdictions means various agencies	• Compatible two-way mobile radios • Center-to-center data-sharing technologies
Funding	• Mainly state and federal • Increasing costs of operation	• Local, state and federal sources • Donations, funds • Public/Private partnerships
24-Hour Operation	• Occurrence of incident just before start of rush hour • Additional funding required • Employees used to regular work schedules	• Employee education • Employee benefits • Hiring of volunteers
Jurisdictional Barriers	• Definition of site responsibilities • Legal ramifications • Political sensitivity • Wrong perspectives of each agency	• Executive level review • Legislature required • Site visits to other agencies • Formation of TMT

STEPS TO DEVELOPING A MODEL RESPONSE PLAN

For an incident response to be well organized and all areas thoroughly considered, a forum for all agencies involved in the incident management process should be sought. A step-by-step process needs to be adopted with all issues concerning the response aspect thoroughly dealt with. This section contains steps that can be followed to develop or improve on current response plans so they become efficient and meet the requirements of freeway management in any given area.

Step 1 Identify Stakeholders

The first step is to identify the relevant stakeholders, such as state, city, and county departments of transportation, Metropolitan Planning Organizations (MPOs), emergency preparedness organizations, emergency medical services, fire departments, state and local law enforcement, transit operators, commercial transportation firms, environmental protection, maintenance, towing operators, major employers, user groups, media, elected officials, policy makers and others specific to the region. Critical to the success of a traffic incident management program is the development of a cooperative spirit and consensus among the various stakeholders.

Step 2 Define Problems

The first step in developing an ideal response plan involves a planning process. It is important to define the problem at hand. Incident response involves a planned strategy and should not be rushed into without

first defining the problems of the particular state or county. Taking the FHWA Traffic Incident Management Self-Assessment Guide survey, can start this process.(38) This gives a more broad look at Incident Management but should give an indication of some problems with response procedures.

Step 3 Set Goals and Objectives

Setting goals and objectives are an important step to knowing a department's direction of progress. Goals need to be achievable and within the capabilities of the state DOT, with due recognition of funding constraints.

Step 4 Identify Options / Alternatives

With varying degrees of effectiveness, the administrative, organizational, and pre-planning options can be implemented to improve an existing incident management option. These are outlined below:

Administrative Options

Transportation Management Center. This is a central information processing and control site. In a multi-jurisdictional situation, it is advisable to develop one overall TMC, providing better service than several uncoordinated centers. Since the primary function of TMC is information sharing, it is best to link its operations with existing agencies. Ideally, it would include all of the decision makers involved in a major incident, especially the local police command center. Some of the service patrol vehicles and personnel could also be housed at this center. TMCs not only improve incident management but also impact the whole transportation management system.

Incident Response Teams (IRTs). Incident response teams are most often interdisciplinary teams that are specially trained to handle a range of roadway emergencies. In many cases, those participating from each responding agency (e.g., fire, police, DOT, EMS) often volunteer for this duty. IRTs may comprise from one to several members from each agency, depending on the agency's size and structure, its function and typical incident management involvement, and the frequency of major incidents (1). IRTs are generally authorized to determine a course of action, deploy personnel, and commit their agency's resources. Effective IRTs function as a unified entity. Staffing configurations vary considerably, however the following agencies and service providers may be part of the IRT: service patrols, ambulance services, towing and recovery, transit, toxic material control and emergency services (1,2). However, IRTs are not common as they pose considerable institutional hurdles.

Dedicated Freeway Units. Dedicated freeway units are vehicles and personnel assigned to a freeway in either a full or part-time detection and/or response capacity. Having patrols out on the freeways during high accident periods (i.e. rush hours) can help to reduce response time (27). The most common type of dedicated freeway units are police freeway patrols. These are operated by either the state or local police and are usually composed of vehicles that are specifically outfitted for freeway operations. Patrol cars fitted with push bumpers are an effective way of clearing incidents quickly, and peak hour patrols by police on motorbikes are useful for avoiding traffic and reducing response times. Dedicated freeway units operated by DOTs, citizens groups, and private companies are usually service oriented.

The development of a dedicated freeway unit within a police department provides a great deal of flexibility in dealing with all types of freeway incidents. A notable benefit to the motoring public and the police agency is increased public relationships. However, this option can be expensive as the need for exclusive use of patrol vehicles for freeways, may require purchase of more patrol vehicles and hiring of more officers. Also it may run counter to the operation philosophy of the department, with more officers interested in crime busting than freeway duties (8).

Placement of Response Vehicles. This involves the positioning of response vehicles at selected points, other than at the vehicles' normal dispatching base, on a freeway or point facility. A variation of this procedure is the repositioning of response vehicles to maintain uniform coverage when a single vehicle or squad is dispatched. Depending on historical incident circumstances, these vehicles may be police cars, wreckers, ambulances, fire engines, or any other vehicle type that may be necessary to handle an incident.

The purpose of this option is to decrease response time, particularly to high incident location such as tunnels and bridges, where even minor incidents have serious impacts on traffic flows. An example can be to assign one wrecker at each end of a floating bridge (8). The question of whether this option is cost-effective needs to be looked at, as committing vehicles to specific locations may limit their usage at other places, and careful analysis of incident frequency, location, severity, and effect on traffic is the only way this question can be answered. This option is probably more practical for point facilities.

Equipment Storage Sites. This option utilizes storage facilities at or near high incident locations to store large equipments such as wreckers, sand trucks, and other large vehicles as well as smaller equipments such as cones, flashers, portable barriers and other equipment for traffic control (36). Such a site would reduce response times by providing special removal equipment at high incident locations. Costs are minimal only if space for the storage facility already exists, otherwise it may be difficult to find additional space at some high incident areas.

Administrative Traffic Management Teams (Incident Management Task Force). This is a team of high level officials from participating agencies in the incident management process namely the transportation, police, fire, and rescue agencies. Examples include the Metro Atlanta Traffic Incident Management Enhancement (TIME) Task Force in Georgia and the Working Committee for the I-65 Freeway Incident Management Study in Kentucky and surrounding states forming part of the I-65 Freeway (18,24). The purpose of the TMT is to provide a forum for discussion of unresolved incident management issues, preplanning for response, and improved communications. It is important to have inter-agency reviews of post incident nature and critique to find out how improvements can be made. The goal is to make all agencies feel a part of the IM process at the highest level.

Emergency Vehicle Access. The use of movable barriers and U-turns at key locations along the freeway has the potential of reducing response times for emergency vehicles and should be considered. A study by Urbanek and Colpitts, showed that creating an Underpass to facilitate access by emergency vehicles as well as state troopers while traveling in the opposite direction had a potential of a 63 percent total reduction in average response time (8). Incorporating the design of U-turns into future roadway construction may incur fewer costs than creating these on existing roadways. However, unauthorized motorists may be tempted to use these U-turn facilities, and movable barriers are expensive. Some response agencies cross over medians while others use that as a last resort to get to incidents quickly (32).

Shoulder Travel. In areas where shoulder widths are wide enough for emergency equipment, ordinances governing travel on shoulders is possible. This might be a dangerous option, as responders run the risk of running into vehicles pulling over onto the shoulders. It is advisable to use this option as a last resort, when traffic speeds are extremely low and incident is severe (as in accidents involving injuries), because of the potential for secondary accidents.

Use of Siren/Public Address Systems. This gives incident response teams the option of using sirens to notify motorists of their presence so as to create a path in helping decrease response times to incidents. This is often used as a last resort when responding to a confirmed incident in order to maneuver through heavy congested traffic (32,26). The system should not be used simply to avoid normal traffic congestion and / or to check on an unconfirmed incident.

Automated Vehicle Location and Dispatch. This is a new area being explored by some DOTs (22,24). GPS systems with data links provide the TMC the capability of locating the service patrols and the direction they are headed as well as speed information. Also, an auxiliary port on the AVL unit connecting a data terminal in each patrol vehicle to the main ITS system allows service patrols to transfer real-time roadway incident data directly into the ITS incident management system, bypassing operators and dispatchers at the TMC (25). This eliminates the need for many of the radio transmissions and paper log entries currently being done. Another added advantage is the provision of capability of data messaging between emergency response vehicles, with data messages remaining to alert patrol units when drivers are temporarily occupied or out of communication.

Organizational Options

Law Enforcement/DOT Relationship. This option is defined as the working relationship between these two organizations. Typically law enforcement agencies are more closely coordinated with transportation agencies than are fire and rescue agencies (2). Having police officers on duty at the Traffic Management Centers can facilitate response coordination. Law enforcement and traffic management center personnel must be coordinated, not simply collocated. The two agencies can compliment each other well in the response process. Law enforcement resources will be available to respond to more urgent concerns by drawing on resources such as CCTV for incident verification and service patrols to respond to disabled vehicles. The use of law enforcement personnel on motorcycles for incidents occurring during peak travel periods can improve response times.

Relationship with other Agencies. This is the development of working relationships between the agency with primary incident management responsibility (generally a police or highway department) and other public agencies or public-spirited organizations that perform specialized or backup incident management functions. Establishing an incident management – oriented relationship with other public agencies or interested organizations is an organizational option that is highly cost-effective.

Wrecker/Tow Truck/Removal Crane Contract Agreement. These contracts may be established with private firms to reduce response times at frequent incident locations, and to allow immediate use of necessary equipment. These contracts help eliminate any questions of who to call when specific equipment is required. Agency owned tow trucks are typically costly to purchase and operate. Private contracts offer financial incentives for the tow truck company to arrive faster and clear freeway as quickly and safely as possible. This has all the added benefits of dealing with the same company (39).

Improved Inter-Agency Information Sharing / Communication. Information sharing among agencies is a key aspect in developing a more efficient response process. To facilitate this, inter-agency radio communication should be enhanced and this may require the purchase of compatible two-way radio equipment and the use of a common nomenclature or terminology. This would help provide better information to the respondent personnel as well as improve site management. Costs vary depending on specific equipment needs, and it may not be feasible for all agencies to invest in new equipment. However, when two or more agencies are involved, a command center may be necessary and this facility will improve communications and save time by reducing repetition of commands.

More technologically - advanced means of inter-agency communication and thus information sharing are on the horizon. The Georgia DOT currently has a demonstration project to exchange information electronically between their system and the City of Atlanta 911 Center. This is a model project demonstrating center-to-center data-sharing using CORBA (Common Object Request Broker Architecture) technology (24). These are new technologies that are still being developed and may not work fully; hence current benefits are limited.

Pre-Planning Options

Personnel, Equipment and Material Resource List. A personnel list detailing those to respond to an incident from any particular segment can be an effective tool. Police, fire, EMS, transportation, media, and private agency contacts as well as the method of communication would be specified. Agency jurisdictions as well as radio channels and telephone numbers should be clearly identified. This list should be distributed to the appropriate responding agency personnel. A similar list for equipment and materials in the area should be compiled, as well as where to locate these. This is a relatively inexpensive tool, with low capital cost and no special operating costs required, that can save time and effort in the event of an incident. However, keeping this current may be difficult and initial difficulties may arise in obtaining agency cooperation.

Incident Response Manual. Although some of the TMCs contacted did not have a specific response manual, they all had documented processes for responding to incidents and / or had plans of putting together one. This manual is a simple, easy to implement and cost effective tool for DOTs. It can be a loose leaf manual and can contain a supplementary directory containing the location of the primary response personnel and the any backups, and off-hours telephone numbers of all possible incident management participants and other informational items such as schematics of complicated interchanges and milepost identifiers (36).

The Georgia DOT and Florida DOT have an excellent example of an Incident Management Procedures Manual, whiles Georgia DOT and Maryland's SHA both have a detailed Operating Procedures Manual for their response teams (26,27,40). The range of this option depends on the level of comprehensiveness desired by the agency. A Table of Contents of the Georgia DOT's HEROs Operating Procedures Manual is shown in Appendix B.

Incident Priority Identification. A well-defined classification of the severity of incidents needs to be outlined. This may form part of a dispatcher's manual for response teams. It will classify incidents by severity levels and corresponding nature of agencies and equipments required to deal with the incident as well as the number of personnel required.

Personnel Training Program. This emphasizes the coordination aspect of incident response, making each agency aware of the other agencies' needs and requirements. A demonstrated willingness to participate and cooperate is required by all agencies if the incident response team approach is to be successful. Inter-agency personnel training is recommended to ensure that any rough edges in communication and coordination are smoothed out before any major incident occurs. Training of field personnel in their own incident management tasks must be complemented by an understanding of the duties and abilities of other agencies and the importance of cooperation among all agencies involved.

Communication Training. The communication training option will involve the instruction of telephone and radio operators in proper voice communications techniques for reporting and receiving information about freeway incidents. This may include following the FCC regulations that govern radio transmissions, using a standard reporting format to ensure accuracy and completeness, and practicing good voice quality and pronunciation so that messages are intelligible. These techniques should be made available through some active format to all the people who engage in incident – related communications including FIM agency dispatchers, police patrolmen, highway maintenance personnel, and civilian CB radio operators (8).

The purpose of a communication-training course is to eliminate errors and minimize communication time as this is critical in ensuring that responders arrive in time to clear incidents. Radio communication in particular has a high tendency for interference and overloading and training is especially important. To overcome this, communications to responders as regards the location of incidents must be provided clearly based on a common frame of reference.

Public Education. This is a user-related option, which seeks to refine the public's participation in Incident Management. About 50 percent of all people who call in to report incidents have no idea of their exact location (36). To counter this, public relations need to be improved with motorists being made aware of the need to be conscious of their surroundings. Cell phone operators or sales persons can be utilized to advise motorists of the need to be accurate in their reporting of incidents on freeways.

Closely Spaced Reference Markers. Installing closely spaced reference markers for instance every tenth of a mile is a good way of helping motorists be more specific of incident locations (36). This also allows for more accurate location of accidents by incident response personnel as well as improving the speed with which additional response vehicles can reach the scene and clear the incident. It also provides information for a simplified automated record keeping and analysis of incident response measures by geographic location.

Alternate Route Planning (Re-routing). Diversion Route planning is a useful option when the capacity of the freeway is reduced by an incident. It is important to plan routes that avoid low overpasses or severe turns. Appropriate temporary or permanent signings are required at junctions and along the route to reduce confusion and provide for smooth traffic flow. Use of CMS and/or HAR to inform motorists of the alternate routes has proved effective (1,2,19,18). A reduction in traffic congestion will facilitate quicker responses especially from secondary response teams like EMSs, fire personnel and HAZMAT clearance teams.

Another rerouting option will involve communicating to the response teams, the less congested and quickest routes to the incident scene. This aspect is a useful tool that can be done with the help of GPS facilities in the TMC and adequate communication facilities. General directions to the incident scene can be initially given to the responders with more specific details given as they maneuver their way to the scene.

Summary of Options in Incident Response process

Tables 4a, 4b and 4c following, summarize options outlined above for reducing response times in an incident management program. Agency involvement in these various options has also been given in the table. Potential benefits have been given as a means of identifying the overall positive impact of any given option towards improving the response process. The potential costs associated have been obtained by considering costs including capital, maintenance, operating, and special equipment and training needs.

Step 5 Implement Alternatives

After identifying all available alternatives to the department, the next step is peculiar to the location and particular characteristics of the area of operation of the TMC. Issues such as funding, agency policy, and legislature govern the selection and implementation of the alternatives available. Careful consideration of these issues needs to be done, with the alternatives selected being cost-effective, efficient, effective and appropriate for the particular area of operation.

Step 6 Data Collection

A conscious effort needs to be made to collect data from the incident response process. Both quantitative data as well as qualitative data must be taken into account. Quantitative assessment will include:

- The number of cooperating agencies in the response process;
- The amount of incidents responded to during the past year;
- The response times recorded by the various TMCs; and
- The number of secondary accidents involving responders en route to the incident scene.

Qualitative data collected might include:

- Survey feedback from the public;
- Feedback from Responders;
- Feedback from TMC operators; and
- Feedback from other agencies involved in the incident response plan.

Table 4a. Administrative Options in Incident Response Process

Administrative Options	Potential Benefits	Potential Costs	Agencies Responsible	Comments
Traffic Operations Center	☀☀☀☀	\$\$\$ → \$\$\$\$	DOT	Provides single location for monitoring incidents and coordinating appropriate responses by collecting information from various sources
Incident Response Teams	☀☀☀	\$ → \$\$	DOT, police, fire, rescue, EMS	Interdisciplinary teams specially trained to handle a range of roadway emergencies. Should function as a unified entity.
Dedicated Freeway Units	☀☀☀	\$\$ → \$\$\$\$	DOT, police, private agencies	Potential for reducing response time required for dispatching from TMC.
Administrative Traffic Management Teams	☀	\$\$	DOT, police, fire, rescue and public works	Forum for discussing improvement of response process including funding opportunities.
Equipment Storage Site	☀☀☀	\$ → \$\$	DOT, police, fire, rescue, private agencies	Provides faster access to equipment and materials.
Traveling on Shoulder	☀	\$	DOT	Provides additional lanes for response vehicles; limited by space.
Placement of Response Vehicles	☀	\$	DOT, police, and private agencies	Helpful on point facilities; limits effectiveness in other incident occurrence elsewhere.
Emergency Vehicle Access	☀☀☀	\$\$	DOT, police, EMS, fire, rescue and private agencies	Can reduce response times; need to identify freeway links with poor access.
Automated Vehicle Location and Dispatch	☀☀☀☀	\$\$\$	DOT, police, fire and rescue, private agencies	Potential to improve dispatching and response times if accurate.

Step 7 Re-evaluate Alternatives

This re-evaluation needs to be done at the highest level by the TMT or incident management task force, which will bring the opinions of all participating agencies to the board. An example of a detailed data collection for all aspects of an incident management plan can be obtained from the CHART operations website hosted by the University of Maryland at College Park ([28](#)).

Table 4b. Organizational Options in Incident Response Process

Organizational Options	Potential Benefits	Potential Costs	Agencies Responsible	Comments
Wrecker/Tow Truck/Removal Crane Contract Agreement	☼☼	\$→\$\$	DOT, private agencies, media	Provides faster access to equipment; likely dissention with other capable private agencies.
Improved Inter-agency communication / information sharing	☼☼☼☼	\$→\$\$	All agencies	Helps in locating closest vehicle to incident; however agencies' priorities may differ.

Table 4c. Pre-planning Options in Incident Response Process

Pre-planning Option	Potential Benefits	Potential Costs	Agencies Responsible	Comments
Personnel, Materials, and Resource List	☼☼☼☼	\$	All agencies	Saves time in locating needed personnel, materials, and equipment; frequent update needed
Incident Response Manual	☼☼☼☼	\$→\$\$	DOT	Provides guidelines and options for responding to incidents; the more detail, the better.
Communication Training	☼☼	\$	DOT, police	Potential to reduce length and repetition of information to responders.
Personnel Training Programs	☼☼☼☼	\$→\$\$	All agencies	Potential to reduce response time with more knowledgeable and better-equipped operators
Public Education	☼☼☼☼	\$→\$\$	DOT, police, media	Helps decrease incident, response times and responder safety.
Incident Priority Identification	☼☼☼☼	\$	DOT, police	Provides easy decision for responders in case of dual incident occurrence.
Closely Spaced Reference Markers on Freeways	☼☼☼☼	\$	Police	Provides, fast, accurate and easy incident location identification for quicker responses
Alternate Route Planning	☼☼	\$	DOT, Police	Potential for quicker access to incident site by response vehicles (if carried out properly done)

☼ = minor benefits

☼☼ = moderate benefits

☼☼☼☼ = Substantial benefits

☼☼☼☼☼ = Extremely substantial benefits

\$ = minor costs

\$\$ = moderate costs

\$\$\$ = Substantial costs

\$\$\$\$ = Extremely substantial costs

Step 8 Document Benefits

A documented process evaluating the benefits accrued after the implementation of the response process needs to be done. This will identify what is working well in the incident response and by how much. This is also important as a source of information to policy makers and as a means of assuring them of the effectiveness of the process. It also increases the likelihood for continual support from the legislature as well as funding agencies.

Step 9 Refine Response Process

A re-evaluation of the response process will identify any loopholes in the response plans. Even though response times may be impressive, any small improvements or reductions is always beneficial and should be pursued whenever possible. Hence, a refining of the response process is desirable to further ensure that incidents are responded to promptly, with all delays that can be eliminated are eliminated.

PANEL REVIEW OF MODEL PLAN

Two transportation engineering persons with extensive knowledge and experience in incident management were given the opportunity to critique the response plan developed. Their general comments are presented below (41):

- It is important that the plan recognizes the value of contract wreckers. Response time, dealing with the same company, available resources are just some of the benefits brought by this option.
- It was good to mention inter-agency radio and telephone communication, as this is a significant problem.
- Personnel contact list is important and an office should be identified to keep it current as an outdate list could occur the day after it is published and this is very discouraging to field personnel.
- Incident response manual is very important to seasoned responders as well as to rookies (more so to the rookies).
- A discussion of measures of effectiveness is needed when considering goals and objectives.
- Alternate routing discussion is good and shows the value of a TMC to respond to lessen impact to traffic.
- It is important to mention performance measures when speaking of goals. There is a saying that is currently popular dealing with the importance of performance measures that says, “What gets measured gets done.”
- It is not necessary to have everyone physically in the same place if they have electronic information sharing. In most cases co-habitation is not feasible. It is also important to mention the importance of ITS technology in incident management. CCTV cameras for detection and confirmation, and CMS for disseminating incident information to motorists are invaluable IM tools.
- As an example of DOT/law enforcement relationship, a DOT TMC operator could be sent to work in the 911 center during peak hours to quickly advise the TMC of reported incidents that may affect traffic.
- Good relationships with the private sector, for profit-making incident responders, such as towing and recovery and Hazmat cleanup companies are very important to the success of the IM program.
- Contracting wreckers needs to be carefully done as it may also cripple the DOT’s ability to get help from more qualified wrecker or one more experienced in handling major recovery efforts. Often who is on contract is not the best company to do the work. Make sure strict requirements as to equipment and experience are laid out and enforced for all companies given contracts. It doesn’t matter if they get there fast if they can’t do the job.

- Important to train TMC operators on what to ask from whom and when. It is very important for them to get the important information first, and not bog down on-site responders with a lot of questions that are not really necessary at the time, and could be answered later.
- It is important that adequate information is known about the alternate route so that motorists are not diverted to another more congested condition. Alternate routes must be constantly checked to make sure they do not become overloaded. If they do, the alternate should be discontinued. Motorists get really frustrated when you send them off into a route that is as congested, or even more congested, than the one they were on.

AUTHOR'S CLOSURE

Based on the comments from the expert panel, it was realized that a detailed summary of measures of effectiveness was needed to complete the plan outlined and this is shown in Table 5.

A variety of incident response options have been outlined by various agencies and the resulting plan has tried to take into account the different alternatives that may be considered in any response plan. The suitability of any particular option, however, is very much dependent on local conditions. An attempt has been made to develop plans with options for low-budget and large-budget agencies but the particular needs of a local area is a critical factor in applying any particular plan intended for responding to incidents on freeways.

RECOMMENDATIONS

General Recommendations

Incident Management and specifically incident response is a constantly revolving art or system that should continue to improve and continue to adapt to the changing needs of the local area. This evolution must continue to meet the needs of the participating agencies, the affected jurisdictions, and the motoring public. Reviews of current standards and practices need to be conducted and new goals and objectives must be continuously set and aimed for. This will ensure that the continually increasing traffic population with its attendant problems in the increase in incidents does not take the transportation sector by surprise.

It is important to note also that incident management involves some five main aspects and since Incident Response is just a part of this, a holistic approach to incident management to involve the application of ITS technologies or roving patrols to detect and verify incidents quickly, as well as sound incident site management and traveler information plus quick clearance of incidents should be part of any incident management review and initiative. Improving overall traffic incident management process will improve the safety of responding agency personnel, reduce the chance of secondary crashes occurring in the unexpected traffic backup and reduce the overall delay travelers' experience.

Recommendations for Future Research

The focus of this research was on the response aspect of incident management. As noted in the paper, the other areas of incident management are just as crucial. Perhaps an area with a greater potential for gains is in incident clearance (42,43). Further research needs to be done to explore the ways in which incident clearance times can be improved, including quick clearance legislation, as well as ways of improving the safety of both clearance teams and motorists during major incidents.

Table 5. Measures of Effectiveness for Evaluating Responses to Freeway Incidents

Transportation Issue	Performance Criteria	Measure of Effectiveness
Institutional	Enhanced agency activities	• Reduction in personnel hours required to perform necessary functions
	Increased level of cooperation among agencies	• Reduction in response and clearance times • Amount of inter-agency communication • Number of inter-agency incident management meetings • Trend in attendance at incident management meetings
Safety	Increased safety of responders	• Accident rate of responders
	Increased safety of motorists	• Number of secondary accidents involving motorists
Efficiency	Timeliness	• Average response time • Reduced total time incidents from verification to recovery
	Service Patrols	• Quality and quantity of motorist correspondence from distributed post cards • Qualitative assessment of operator morale • On time performance of operators • Increased accuracy in communication among TMC, service patrols and other response agencies
	Increased TMC efficiency	• Automated detection and verification of incidents • Changes in travel time • Changes in incident verification, response, clearance and recovery times
User Related	Level of Public Approval	• Qualitative assessment of public approval
	Extent of Public Participation/Education	• Qualitative assessment of public education programs • Qualitative assessment of communication with public • Percentage of callers knowing exact location of incident

Emerging trends in ITS application need further research to determine their effectiveness and potential to impact the incident management process in a positive way. Automated Vehicle Location and dispatch systems are being used in Georgia and a few other states. This provides a means of automatically locating service patrols and sending information via data messaging. Advanced vehicle control systems are also being developed to help minimize the occurrence of incidents. Further research can be done to

improve this system, and seek ways of making it cost-effective so that smaller agencies can manage to implement this system and reduce the gulf in response times. The same can be done for interagency communication tools such as the use of CORBA system or other means of ensuring center-to-center data sharing among agencies.

An important area of incident response is the development of an Incident Response Manual. However a lot of DOTs still do not have such a manual for their response teams and / or service patrols. Further research can be done to examine the relevant information that needs to be part of such a manual.

ACKNOWLEDGEMENTS

This paper was developed and written as part of the graduate course CVEN 677 *Advanced Surface Transportation Systems* at Texas A&M University. The author would like to thank Dr. Conrad Dudek for allowing him to participate in this program and be involved with some of the most outstanding professionals in the transportation field. Special thanks must go to the author's professional mentors, Dr. Walter Kraft, Senior Vice President of PB Farradyne, and Mr. James Wright of the Minnesota Department of Transportation, for their insightful help in writing this paper. The author would also like to extend his heartfelt appreciation to the other 2003 mentors: Marsha Anderson Bomar, Wayne Shakelford, Gary Trietsch and Thomas Werner for their advice, and devotion of time and expertise.

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The following DOT personnel were kind enough to respond to the surveys and the author herein expresses his gratitude to them:

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- Sue Groth of the Minnesota Department of Transportation;
- Richard Knowlden of the New York State Department of Transportation;
- Glenn McLaughlin of the Maryland State Highway Administration;
- Bruce Pettus of the Missouri Department of Transportation; and
- Everett Townsend of the California Department of Transportation.

Finally, the author wishes to thank God for the strength and grace He gave him to focus on and complete this paper within the stipulated time period.

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APPENDIX A : SURVEY TO AGENCY CONTACTS

Incident Response Survey

TOPIC: MODEL RESPONSE PLAN FOR FREEWAY INCIDENTS

Please, feel free to either make responses directly to this form in Microsoft Word, or to print this form out with either extra space for your answers or use additional sheets of paper to complete your responses. **All responses should be mailed, e-mailed, faxed or phoned to Kwaku Obeng-Boampong by June 30, 2003.** There may be need for clarification with regard to your responses, please provide the best and the preferred means to contact you. Any questions with regard to this survey can be directed to Kwaku Obeng-Boampong.

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1. What is the general process of responding to incidents?
2. What works well and what doesn’t work well?
3. Do you have a manual for response teams or documentation of response process and if yes, can I get a copy?
4. What are the hours of operation of freeway units?
5. What is your budget allocation to Incident Management? What is the source of funds?
6. Can you tell what percentage of this goes specifically into the area of response?
7. What is the average response time?
8. Is this response time dependent on the type of incident?
9. What other factors affect the way response tasks are conducted?
10. What other factors affect your response times (e.g., volume of traffic on freeway, configuration of freeway (two, three, four way lane), availability of appropriate response teams)?

11. What role does ITS (technology) play in helping response time reduction?
12. What is the means of communication among your response teams?
13. How does interagency integration help in response time reduction?
14. In your opinion are there other ways of improving freeway incident response?
15. Are there some simple, common sense applications that can be used to reduce the response times to freeway incidents? (E.g. do you send response team out prior to giving them specific directions as to where the incident occurred?)

APPENDIX B : GEORGIA DEPARTMENT OF TRANSPORTATION - H.E.R.O. UNIT STANDARD OPERATING PROCEDURES TABLE OF CONTENTS

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2.5	Uniforms and Personal Appearance
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3.9	Motorist-Aid Protocol
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These sections contain diagrams and drawings outlining various procedures:

310. Emergency Warning Lights and Arrow Board Protocol
311. Protocol for Responding to Incidents
312. Relocating Disabled and Abandoned Vehicles
313. Communication with TMC
314. Traffic Control Procedures

KWAKU OBENG-BOAMPONG

Kwaku Obeng-Boampong received his Bachelor of Science Degree in Civil Engineering in July 2001 from the Kwame Nkrumah University of Science and Technology, Ghana where he graduated with First Class Honors. During that period he had internships with various consulting firms, including undertaking assistant supervisory roles in the expansion of the Coca Cola Bottling Company of Ghana Ltd. (CCBCGL) factory. The works carried out included Pavement Construction, Drainage Improvement, Septic Tank/Biological Filter construction, installation of a Raw Water Steel Tank and Structural Steel works as part of the extension of CCBCGL's Production Building and Loading Canopy.



Part of his undergraduate work experience also involved traffic data collection at a major temporary car park located in the CBD of the capital Accra, and subsequent analysis of data collected from this survey. Purpose was to establish the validity of construction of a new multi-storey car park and predict generation of parking around the proposed site for construction.

His senior year project involved the improvement of road network in one of the highly populated rural communities in Ghana. The project involved the geometric design of roads and layout of road network using the MX Road software and AutoCAD, with the implementation of mitigation measures to improve road safety to both vehicles and pedestrians.

He is currently pursuing a Master of Science degree in Civil Engineering at Texas A&M University while working as a Graduate Research Assistant at the Texas Transportation Institute (TTI), where he is working on an evaluation of a system giving vehicles advance warning for end of green phase on high speed rural intersections. His areas of interest include geometric highway design, traffic safety and operations, human factors and performance, transportation planning and intelligent transportation systems. He recently got accepted into the Phi Kappa Phi honor society of Texas A&M University which admits the top 10 percent of all graduate students, and is a member of the International ITE, the Texas A&M University Student Chapter of ITE, the Institute of Civil Engineers (in the UK), and the Ghana Institute of Engineers.

SAFETY MEASURES FOR PEDESTRIAN CROSSINGS IN THE UNITED STATES

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Advanced Surface Transportation Systems

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SUMMARY

As more people desire to travel by walking, the need for effective pedestrian safety treatments will continue to rise. In the United States in 2001, over 77,000 pedestrian injuries and over 4,800 pedestrian deaths were caused by motor vehicles (1). The large number of pedestrian injuries and fatalities each year illustrates why pedestrian safety should be a top concern for engineers and planners.

In this project, specific, physical pedestrian safety treatments were examined by the author. The treatments included crosswalk markings, traffic calming, and pedestrian warning devices. A literature review was conducted to gather information on the specific treatments, and personal and telephone interviews were conducted with engineers and planners to supplement the literature review.

Several treatments were analyzed, and guidelines were created for their use. The author concludes the paper with three case studies. Three existing pedestrian crossings in College Station, Texas were evaluated and improvements were suggested based on the guidelines produced in this paper.

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INTRODUCTION

As more communities work toward a pedestrian friendly environment, the need for effective pedestrian safety measures will continue to grow. The desire to travel by walking has grown not only as a means to avoid or reduce congestion on the roadways, but for health reasons as well.

In the United States in 2001, there were 4,882 pedestrian deaths and 77,619 pedestrian injuries caused by motor vehicles (1). Clearly, pedestrian safety should be a top concern, particularly at designated pedestrian crossings. Pavement markings, signage, and other pedestrian improvements can play a significant role in pedestrian safety.

In many cases, improvements specific to the roadway characteristics are necessary. Some improvements may be beneficial for a pedestrian crossing on one type of road but not on another, and roadway characteristics such as speeds and volumes may help the designer designate which improvement to implement.

Ultimately, many devices and technologies exist for use at pedestrian crossings, and some are more effective than others at providing safety for pedestrians. The author examined many pedestrian safety improvements. Due to the large number of pedestrian injuries and fatalities each year, there is a definite need to examine these improvements. Upon examination, the most effective improvements can be matched with the most appropriate locations and applications.

Objectives

The purpose of this research was to identify physical measures used to enhance pedestrian safety at pedestrian crossings, determine the most effective measures, and apply these findings to existing pedestrian crossings. Specifically, the objectives of this research were:

- Perform a literature review and conduct interviews to identify physical roadway and crossing improvements and pedestrian crossing facilities designs used to enhance pedestrian safety;
- Utilize results from the first objective to determine which improvements and designs are most effective at enhancing pedestrian safety;
- Make recommendations as to the improvements and designs that provide the most safety for specific roadway characteristics; and
- Conceptually apply recommendations to existing pedestrian crossings through an audit of crossings in College Station, Texas.

Scope

The scope of this research included physical improvements to roadways and pedestrian crossings as well as pedestrian crossing facilities designs. Primarily, the improvements included physical changes to the roadway and crossing such as raised crossings, refuge islands, and curb extensions. Additionally, improvements including signage and warning (flashing) lights were considered. The pedestrian crossing facilities designs included particular crossing types such as angled center refuge crossings and channeled center refuge crossings.

Although many other types of pedestrian safety improvements exist, only those mentioned were included in this research. Pedestrian crossing signals, grade-separated crossings, and school crossing treatments were specifically excluded from the scope of this research.

Study Design

In order to complete the objectives of this research, four tasks were accomplished. These tasks are described below.

Literature Review

A literature review was conducted to identify physical safety improvements for pedestrian crossings. This review helped the author identify pedestrian safety improvements in such areas as marked crosswalks, medians/refuge islands, signage, and others.

Professional Interviews

To supplement the literature review, telephone and personal interviews were conducted with engineering, planning, and design professionals. The purpose of the interviews was to verify that the improvements found in the literature review were still currently being used and to learn of additional improvements not found in the literature review.

Guidelines for Implementing Pedestrian Improvements

Before suggestions can be made as to which pedestrian safety improvements can be used, the roadway characteristics must be known. Therefore, guidelines were developed to provide suggestions on improving pedestrian safety at crossings for different types of roadway classes, volumes, and speeds.

Case Studies – Intersection Audit

Three existing pedestrian crossings were documented and analyzed for this research. The guidelines were applied to each crossing, and recommendations were made for each of the crossings.

Report Organization

This report is divided into five sections. This section contains the objectives, scope, and study design. A detailed discussion of background information is presented in the next section. Specifically, section 2 provides descriptions of many types of physical pedestrian improvements. Section 3 includes guidelines for implementing various pedestrian improvements.

The fourth section consists of three case studies. In section 4, three existing pedestrian crossings are analyzed, and pedestrian improvements are recommended. The concluding section provides recommendations for future research in this area.

BACKGROUND

Every user of a transportation system has a right to use that system safely, and one type of user, the pedestrian, requires this safety every time he attempts to cross a roadway. Many tools exist to provide safety to pedestrians, and a crosswalk is one of these tools. According to the 1992 Uniform Vehicle Code, a crosswalk is defined as: (2)

- (a) That part of a roadway at an intersection included within the connections of the lateral lines of the sidewalks on opposite sides of the highway measured from the curbs, or in the absence of curbs, from the edges of the traversable roadway; and in the absence of a sidewalk on one side of the roadway, that part of a roadway included within the extension of the lateral lines of the existing sidewalk at right angles to the centerline.

- (b) Any portion of a roadway at an intersection or elsewhere distinctly indicated for pedestrian crossing by lines or other markings on the surface.

Therefore, crosswalks need not be marked because they exist at any public intersection if there is a sidewalk on at least one side of the street. However, crosswalks can also exist at mid-block locations. At these locations, the crossing must be marked for the crosswalk to legally exist.

Crosswalks can have many different safety treatments including pavement markings, refuge islands, and signage. Some of the available treatments for crosswalks are discussed in this section.

Marked Crosswalks

Marked crosswalks utilize pavement markings to delineate the pedestrian walkway to pedestrians and motorists. Standard markings consist of two parallel white lines, but diagonal or longitudinal lines are sometimes added to increase visibility (3). Many marked crosswalk patterns may be used, and Figure 1 illustrates some of these patterns. Typically, the continental, zebra, and ladder markings are considered to be high visibility markings.

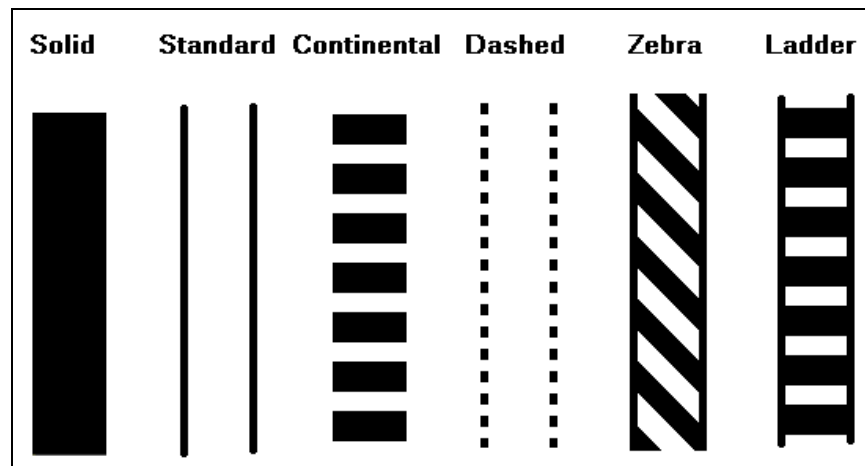


Figure 1. Marked Crosswalk Patterns (Adapted from 4)

In addition to these marked crosswalk patterns, which are usually applied to the surface of the road with paint or other materials, colored crosswalks may be used to increase driver awareness of the crosswalk. Figure 2 includes a visual description of an intersection that utilizes colored crosswalks. Also, textured crossings may be used. These crossings use bricks, pavers, or stamped concrete to increase driver awareness by increasing noise and vibration (5). In addition to the possible increased driver awareness, textured crossings can add aesthetic value to the crossing.

Although many believe that marked crosswalks provide added safety as compared to unmarked crosswalks, several studies revealed that improved safety could not be shown for marked crosswalks as compared to unmarked crosswalks (6,7). In a recent study, Zegeer et al. found that on multi-lane roads with volumes greater than 12,000 vehicles per day, having a marked crosswalk was associated with a higher pedestrian crash rate when compared to an unmarked crosswalk (6). One possible explanation for this result is that pedestrians feel safer when crossing at a marked crosswalk (3). These pedestrians may feel that the motorists can see the marked crosswalk when, in fact, they cannot.

Zegeer et al. also recommended that crosswalk markings alone should not be used where the speed limit exceeds 40 mph (6). Ultimately, these studies suggest that adding a marked crosswalk without any other

crossing treatment would not be expected to reduce pedestrian crashes. Therefore, additional treatments may be added to marked crosswalks.

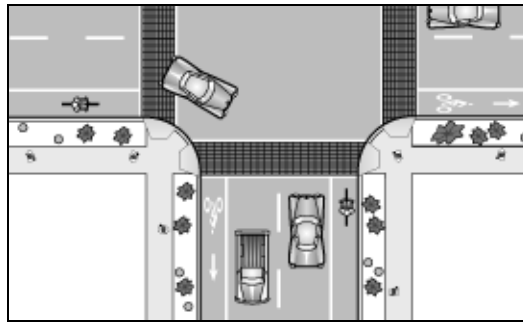


Figure 2. Colored Crosswalks (8)

Raised Medians and Refuge Islands

In order for a pedestrian to cross in an area that is not controlled by pedestrian signals, he must wait for an appropriate gap in vehicle traffic to cross the road. Typically, as the roadway becomes wider, the gap necessary for a safe pedestrian crossing becomes larger. Additionally, a pedestrian attempting to cross two directions of traffic will typically wait longer for an acceptable gap than a pedestrian crossing only one of those two directions. Sometimes, as pedestrians are faced with long delays, they may accept a gap that is too small, and the safety of the pedestrian is compromised. Raised medians and refuge islands can help alleviate this problem.

In a recent study, Bowman and Vecellio determined that the pedestrian accident rate was significantly lower for roadways with raised medians as compared to undivided roadways in both central business district and suburban areas (9). Raised medians and refuge islands may increase pedestrian safety by allowing the pedestrian the option of accepting a shorter gap to cross only one direction of traffic at a time.

As an example, a pedestrian traveling at four feet per second will need a 12-second gap to cross both directions of traffic on a 48-foot roadway, but if a median is added, two 6-second gaps are required to cross each direction of traffic. Since, statistically, two 6-second gaps are more likely than one 12-second gap, the pedestrian may be able to cross safely and with lower delay. This point is illustrated in figures 3 and 4.

Raised medians typically run one or more blocks while refuge islands are much shorter (100 to 250 feet) (10). Also, the width of medians and islands should be at least 8 feet in order to provide adequate space for the waiting pedestrian (10,11); however, the minimum requirements for islands are a 4-foot width and a 12-foot length (12). The use of a refuge island as compared to a raised median will depend on the space and funding available and the need for access management measures. For example, if land access is to be restricted, raised medians can be used.

When used with crosswalks, raised medians and refuge islands should have at-grade cuts instead of ramps to allow for wheelchair access. One reason for this is that there is insufficient space for incline and decline ramps at a median. At-grade cuts are necessary if the crosswalk intercepts the median at a mid-block crossing, or if the raised medians extend through the crosswalk at an intersection.

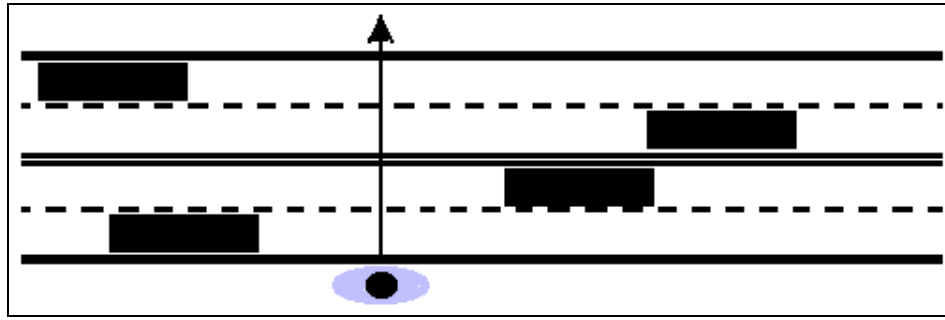


Figure 3. Mid-block Crossing Without Median (Adapted from 10)

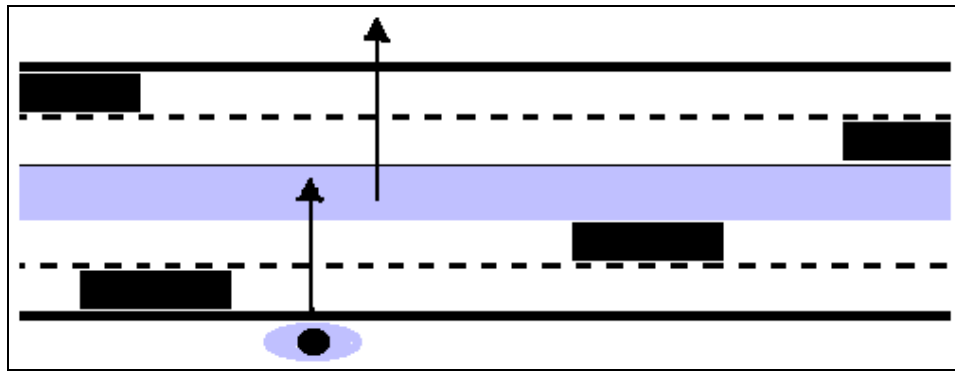


Figure 4. Mid-block Crossing With Median (Adapted from 10)

There are two specific crosswalk designs that utilize raised medians or refuge islands. They are the angled center refuge crossing and channeled center refuge crossing. A schematic of the channeled center refuge crossing is provided in figure 5.

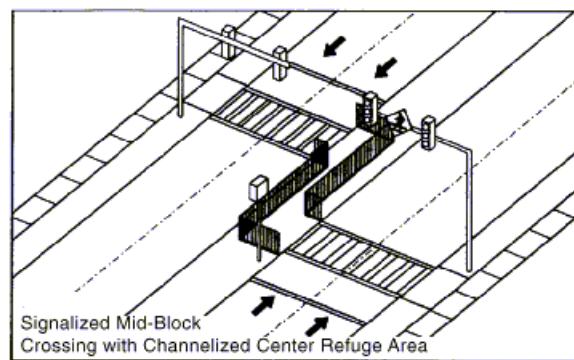


Figure 5. Channeled Center Refuge Crossing (Adapted from 13)

Each of these two designs requires the pedestrian to look at the oncoming traffic before proceeding across the second part of the crossing. In some cases, railings are used to direct pedestrians to the right thereby increasing the likelihood of the pedestrian looking for cars coming from his right (6).

Refuge islands can be beneficial on multi-lane streets with high vehicle and pedestrian volumes and high speeds and on wide streets where the elderly, disabled persons, and children cross on a regular basis (12). However, raised medians and refuge islands will not be beneficial if a substandard width is used.

Traffic Calming

The goals of traffic calming treatments are to reduce vehicle speeds and to improve pedestrian safety, and traffic calming is a useful tool for crosswalks. A traffic calming treatment incorporates a physical change to the roadway, and this change is either vertical or horizontal in nature. Vertical changes include raised crosswalks and raised intersections while an example of a horizontal change is a curb extension, which is a horizontal extension of the curb into the roadway.

Raised Crosswalks and Raised Intersections

Raised crosswalks and intersections are designed to allow pedestrian crossings to be easily seen by approaching motorists, and to cause motorists to reduce their speeds when approaching and crossing these treatments. Not much research has been done to quantify the effects of raised crosswalks on vehicles speeds; however, in a study for the City of Cambridge, Massachusetts, Watkins found that for one particular street, the 85th percentile speed dropped from 31 mph to 26 mph after a raised crosswalk and other traffic calming measures were added (14). Similarly, the percent of vehicles exceeding 25 mph dropped from 57 percent to 17 percent (14). In the same study, Watkins found that a raised crosswalk increased the number of drivers yielding to pedestrians from 13 percent to 53 percent (14).

Another advantage to raised crosswalks is that no ramps are necessary because there is no change in grade for the pedestrians (11). This can make crossing easier for pedestrians with wheelchairs or baby strollers (14).

Curb Extensions

Curb extensions, also known as curb bulbs, bulbouts, and sidewalk flares, are horizontal extensions of the curb into the roadway. Their purpose is to reduce the width of the vehicle travel way at an intersection or a mid-block crossing (15). In addition to shortening the street crossing distance, the presence of a curb extension may allow motorists and pedestrians to have a better, unobstructed view of one another (15). Also, vehicle speeds may be reduced at the crossing (15). The speed reduction could be due to the fact that the roadway narrows at the crossing and that pedestrians may be seen by the motorists from a further distance.

Curb extensions are ideal for streets with on street parking because they have little impact on vehicular traffic and because they allow the motorist additional sight distance to view the pedestrian (11). If on-street parking already exists on the roadway, the addition of a curb extension will not block vehicle travel lanes; however, if the extensions will block vehicle travel lanes, they are not suited for high-speed arterial and collector streets where vehicular capacity in the right lane is a major concern (11). Often, curb extensions are used to define on-street parking areas. Illustrations of curb extensions are found in Figures 6 and 7.

Pedestrian Warning Devices

Pedestrian warning devices can include warning signs, flashing lights, and other special devices such as safety cones and in-pavement crosswalk lights. Mostly, these warning devices are used at non-signalized locations including mid-block crossings.



Figure 6. Curb Extension at an Intersection (Adapted from 16)

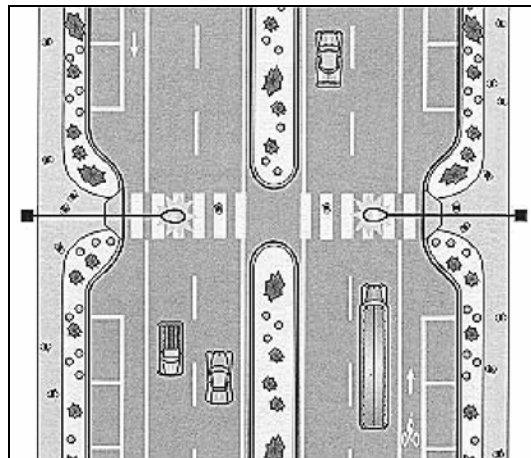


Figure 7. Curb Extension at a Mid-block Crossing (Adapted from 10)

Warning Signs

The predominant pedestrian warning sign is the W11-2 Advance Pedestrian Crossing sign. Typically, it is installed in advance of mid-block crossings or where pedestrians may not be expected to cross. Another sign, the Pedestrian Crossing sign (W11A-2), is intended for use at the crosswalk. The Pedestrian Crossing sign, also called the crosswalk sign, is similar to the Advance Pedestrian Crossing sign, except that it has crosswalk lines printed on it. This could help motorists realize that the crosswalk is adjacent to the sign as opposed to being further up the road. The 1978 Manual on Uniform Traffic Control Devices states that “Crossing signs may be used to supplement Advance Crossing signs as a means of assisting the vehicle operator in defining the specific point of crossing” (17). Although both signs are still used, the 2000 Manual on Uniform Traffic Control Devices (MUTCD) does not include the Pedestrian Crossing sign (W11A-2). The 2000 MUTCD includes only the W11-2 sign and this sign is referred to as the Pedestrian Crossing sign.

The 2000 (MUTCD) states that “[i]f the crossing location is not delineated by crosswalk pavement markings, the crossing sign shall be supplemented with a diagonal downward pointing arrow plaque

(W16-7P) showing the location of the crossing. If the crossing location is delineated by crosswalk pavement markings, the diagonal downward pointing arrow plaque shall not be required.” (18) Both signs may have the traditional yellow background or the fluorescent yellow-green (FYG) background, but the mixing of the two backgrounds within a certain area should be avoided (18). The Advance Pedestrian Crossing sign (W11-2) and the Pedestrian Crossing sign (W11A-2) with the downward pointing arrow plaque are shown in Figures 8 and 9.



Figure 8. Advance Pedestrian Crossing Sign (W11-2)



Figure 9. Pedestrian Crossing Sign (W11A-2) with Downward Pointing Arrow

Mounted Flashing Lights

When used for pedestrian safety, mounted flashing lights are always used in conjunction with at least one other treatment. One example is the Advance Pedestrian Crossing sign with the constantly flashing light (see Figure 10). The intent of the flashing light is to attract the driver’s attention; however, if local drivers become acclimated to seeing the light flashing, there is the possibility that some drivers could lose

respect for the warning (19). Furthermore, the MUTCD states that “[t]he use of warning signs should be kept to a minimum as the unnecessary use of warning signs tends to breed disrespect for all signs” (18). This statement could be extended to refer to flashing lights as well. Although the constant use of these flashing lights is probably not detrimental to pedestrian safety, it should be noted that the inclusion of lights does not guarantee a safer pedestrian crossing.

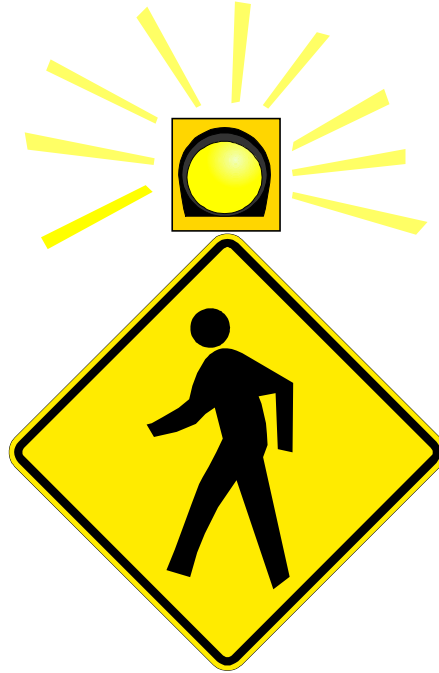


Figure 10. Advance Pedestrian Crossing Sign (W11-2) with Flashing Light

In-pavement Flashing Crosswalk Lights

In-pavement lights are embedded amber flashing lights that are oriented toward oncoming traffic (20). The lights flash as a pedestrian crosses the street, and they can be activated by a push button or by an automated device (20). An illustration of the flashing lights is shown in Figure 11.



Figure 11. In-pavement Flashing Crosswalk Lights (20)

In-pavement lights are a new treatment, and they are not mentioned in the MUTCD. However, some quantifying research has been performed, and the results are positive. For example, Boyce and Van

Derlofske found that adding in-pavement flashing warning lights to a crosswalk that is already clearly striped can make the crosswalk more noticeable to drivers who are not familiar with the location and reduce the mean speed at which vehicles approach the crosswalk (21). One common concern with these treatments is that the crossings may impart a false sense of security to the pedestrians attempting to cross. This is a concern that is relevant to many pedestrian crosswalk treatments, but it may be worthwhile to acknowledge that this could be a problem.

New York Pedestrian Safety Cones

Developed by the New York State Department of Transportation, the New York Pedestrian Safety Cone is a supplementary device that is installed at unsignalized intersections or mid-block locations. It is placed in the middle of the crosswalk, and it bears a sign that states, “STATE LAW – YIELD TO PEDESTRIANS IN YOUR HALF OF THE ROAD.” The cones are made of rubber and are not a hazard to motor vehicles, but the cone should not be used in areas where speed limits exceed 30 mph (22). Figure 12 includes a picture of the safety cone.

A study by Huang et al found that the percent of pedestrians for whom motorists yielded rose from 69.3 percent to 81.2 percent after the cones were installed. The study also found that the percent of pedestrians who ran, hesitated, or aborted their crossing was also reduced after the cones were installed (22). Ultimately, the cones can improve safety with minimal signage; however, they are supplementary devices, so they are intended for use with other treatments such as marked crosswalks.



Figure 12. New York Pedestrian Safety Cone (22)

INTERVIEWS WITH PROFESSIONALS

As a supplement to the literature review, telephone and personal interviews were conducted with professionals who work or have worked in the area of pedestrian improvements. A total of five interviews were completed, and the participants were:

- Joey Dunn and Beth Wilson – Planners, City of Bryan, Texas;
- Sally Flocks – President and CEO, PEDS, Atlanta, Georgia;

- Ken Fogle – Planner, City of College Station, Texas;
- Jeff Olsen – Former NYSDOT Ped/Bike Coordinator; and
- Dan Raine – Houston-Galveston Area Council.

The questions asked during the interviews were designed to supplement the literature review; therefore, the responses were not tabular. The purpose of the interviews was to verify that the improvements found in the literature review were still being used and to learn of additional improvements not found in the literature review. A sample of the questions is included in Table 1.

Table 1. Interview Questions

Have you worked on any projects where safety improvements were made to pedestrian facilities?
If so, what were the reasons for the changes?
What new facilities were used?
Which improvements do you consider to be the most effective at enhancing safety at pedestrian crossings?
Which improvements do you consider to be the least effective at enhancing safety at pedestrian crossings?

The interviews did not yield extensive results; however, some of the responses were informative and helpful. One professional noted that the New York Pedestrian Safety cone was an inexpensive and effective device. During another interview, the city planner prompted a discussion about the effectiveness of continuously flashing warning lights. Finally, one professional noted that “doing nothing” is the least effective treatment for a problematic pedestrian facility.

GUIDELINES FOR USING PEDESTRIAN SAFETY TREATMENTS

Each of the previously mentioned treatments can help improve pedestrian safety if they are used according to guidelines and sound engineering judgement. Some treatments are only to be used as supplements to other treatments, so it is likely that multiple treatments will be an option for some crossings.

The guidelines shown in this section consist of stated roadway conditions and recommended pedestrian improvements for the specific conditions. The guidelines were developed using the information discussed and the studies referenced in the Background section of this paper. Additionally, the recommendations include the use of high visibility crosswalk markings and flashing warning lights, and these recommendations are based on the author’s judgement that these treatments may enhance pedestrian safety at pedestrian crossings that may not be expected by the motorist.

In addition to these guidelines, sound engineering judgement should be used. Pedestrian crossing improvements should not be installed before a pedestrian study has been performed. The guidelines in this section are for pedestrian crossings where appropriate pedestrian volumes exist and where there is a need for pedestrian safety improvements. Table 2 includes the roadway conditions and recommended improvements.

Table 2. Guidelines for Pedestrian Safety Treatments

Conditions	Recommended Improvements
Low Volume, low speed, two-lane roadway.	
<i>Intersection</i>	Marked Crosswalk (Standard)
<i>Mid-block</i>	Marked Crosswalk (High visibility)
Posted speed ≥ 40 mph.	
<i>Intersection (No pedestrian signals)</i>	Marked Crosswalk with additional pedestrian improvements
<i>Mid-block</i>	Marked Crosswalk (High visibility) with additional pedestrian improvements (Recommend Pedestrian Crossing sign and Pedestrian Crosswalk sign)
High volume, multi-lane roadway; and Crossing distance ≥ 60 feet.	
<i>Intersection (Pedestrian signals)</i>	Marked Crosswalk (High visibility)
<i>Mid-block</i>	Marked Crosswalk (High visibility) and Raised Median/Refuge Island
High volume, multi-lane roadway; and Pedestrians having problems seeing vehicles.	
<i>Intersection</i>	Marked Crosswalk (High visibility) and Raised Intersection
<i>Mid-block</i>	Marked Crosswalk (High visibility) and Raised Crosswalk
High volume, multi-lane roadway; Pedestrians have problems seeing vehicles; On street parking; and Crossing distance is to be reduced.	
<i>Intersection or mid-block</i>	Marked Crosswalk (High visibility) and Curb Extension
High volume roadway; and Vertical and horizontal curves limit motorists view of pedestrians.	
<i>Intersection or mid-block</i>	Marked Crosswalk (High visibility), Pedestrian Crossing sign (in advance of the crossing), Pedestrian Crosswalk sign, and mounted flashing lights installed with the Pedestrian Crossing sign

CASE STUDIES

Three existing pedestrian crossings in College Station, Texas were examined and analyzed using the information and guidelines provided in this report. Each crossing is currently operating under conditions that the author considers to be in need of improvement. Each case presents a unique situation that is in need of the application of one or more pedestrian safety treatments.

Case 1 – Mid-block Crossing on Rock Prairie Rd., College Station, Texas

Situation Description

Rock Prairie Rd. is a major east-west arterial with two travel lanes in each direction and a two-way left-turn lane. The posted speed limit is 40 mph, and the average daily traffic is between 12,000 and 15,000 vehicles. Currently, a 10-foot wide ladder marked crosswalk connects the two sides of the street. The distance across the street is approximately 64 feet, but the crosswalk is angled slightly to the right, to allow pedestrians have a better view of the vehicles on the far side of the road. This means that the crossing is actually about 70 feet long. Because this is a mid-block crossing, Advance Pedestrian Crossing signs (W11-2) with constantly operating flashing lights are installed upstream of the crossing. Additionally, Pedestrian Crossing signs (W11A-2) are installed directly adjacent to the crossing.

The crossing allows pedestrians to cross from a large hospital on the south side to the professional building on the north side and vise-versa. Many pedestrians, including elderly pedestrians, cross at this location daily. In addition, both the hospital and professional building have driveway openings directly east of and adjacent to the crosswalk. Finally, the western approach includes a large horizontal curve, which restricts the sight of southbound pedestrians trying to cross the road to reach the hospital.

Figure 13 shows the Advance Pedestrian Crossing sign looking westward (westbound approach). In this picture, the hospital is on the left.



Figure 13. Westward View of Rock Prairie Advance Crossing Sign

Figure 14 shows the crosswalk looking westward with the hospital on the left.



Figure 14. Westward View of Rock Prairie Crosswalk

Figure 15 faces eastward at the Advance Pedestrian Crossing sign. The professional building is on the left in this picture.



Figure 15. Eastward View of Rock Prairie Advance Crossing Sign

Problems and Concerns

The problems as seen by the author are:

- Mid-block crossing;
- Crossing distance > 60 feet;
- Posted speed $\geq$ 40 mph;
- High volume, multi-lane roadway; and
- Vertical and horizontal curves limit motorists' view of pedestrians.

Some concerns of the author are:

- Diverse population using the crosswalk;
- Some pedestrians may have difficulty crossing without a refuge; and
- Lack of local driver respect for flashing lights at the Advance Pedestrian Crossing signs.

Improvements

Applying the guidelines, the author noted that the current conditions were unacceptable because the crossing distance was greater than 60 feet. All of the existing crossing treatments would be used at the crossing along with the recommended improvement.

The recommended improvement for this crossing is a channeled center refuge island, and it could be installed in the median that currently contains a two-way left-turn lane. This would allow the pedestrian a safe refuge in the middle of the road. This means that he can wait for two smaller gaps in traffic as opposed to one large gap. One important note for this improvement is that the refuge island might be short (near the minimum of 12 feet) because room would have to be left for a left-turn lane for the professional building. Most likely, the crosswalk would be laterally shifted to the west to compensate for this requirement.

The final improved crossing at this location would include high visibility markings, Advance Pedestrian Crossing signs with flashing lights, Pedestrian Crosswalk signs, and a channeled center refuge island where the two-way left-turn lane is currently located. Although the crossing will have flashing lights, these may be continuously flashing or they may be actuated by the pedestrian. The author prefers the actuated lights to the continuous lights because of the possibility that local drivers may lose respect for the continuously flashing lights over time.

Case 2 – University Dr. at Wellborn Rd. Entrance Ramp, College Station, Texas

Situation Description

University Dr. is a major east-west arterial with two travel lanes in each direction and a median. Wellborn Rd. is a north-south arterial that intersects University Dr. at a partial cloverleaf interchange. As seen in Figure 16, a ramp connects Wellborn Rd. to the eastbound lanes of University Dr. At this connection, there is a pedestrian crossing that crosses the entrance ramp lane. The crossing does not have pavement markings, and since it is not located at an intersection, no legal crosswalk exists. Nevertheless, this crossing is used daily by numerous pedestrians, most of whom are students at Texas A&M University. The crossing has sidewalk wheelchair ramps that meet the street on both sides, and the distance between the two ramps is approximately 50 feet. Although only one lane is crossed, the ramps are aligned to cross the road at an angle, so the crossing distance is greater than the 16-foot lane in the road.

The posted speed limit is 40 mph for the vehicles on Wellborn Rd., and few vehicles tend to slow down on this part of the road because of the large curve radius. The peak hour volumes for this lane are over 600 vehicles per hour. Pedestrians have a limited sight distance due to the horizontal and vertical curves in the entrance ramp roadway, and vehicles, too, have a limited sight distance as they approach the crossing. No pedestrian safety treatments are currently use at this crossing.

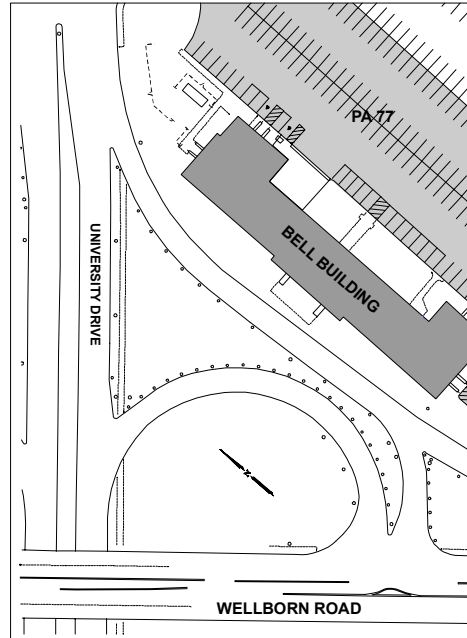


Figure 16. University Dr. at Wellborn Rd. Entrance Ramp (Adapted from 23)

Figure 17 shows an upstream view entrance ramp (looking southward) from the pedestrian crossing.



Figure 17. Southward View of Wellborn Rd. at University Dr.

Figure 18 shows the pedestrian crossing looking eastward with the entrance ramp road entering from the right.



Figure 18. Eastward View of Wellborn Rd. at University Dr.

Figure 19 shows a northward view from the entrance ramp roadway. A pedestrian can be seen on the left waiting for a chance to cross.



Figure 19. Northward View of Wellborn Rd. at University Dr.

Problems and Concerns

The problems as seen by the author are:

- Mid-block crossing;
- No crosswalk markings;
- Posted speed ≥ 40 mph;
- Pedestrians have problems seeing vehicles; and
- Horizontal and vertical curves limit motorists' view of pedestrians.

Some concerns of the author are:

- Lack of a legal crosswalk at the crossing; and
- Crossing unexpected by motorists.

Improvements

Many treatments could be applied to this crossing, and certainly multiple treatments are necessary. For an improvement to this crossing, the author found that the following treatments are necessary. After the guidelines were applied, multiple treatments were recommended. First, a high-visibility marked crosswalk would establish a legal crosswalk at the crossing. Along with this, an Advance Pedestrian Crossing sign and a Pedestrian Crossing sign would provide some warning to the motorists. One advantage of the Advance Pedestrian Crossing sign is that it can warn the driver of the crossing before the crossing is in his line-of-sight.

The final improved crossing at this location would include high visibility markings, an Advance Pedestrian Crossing sign, and a Pedestrian Crosswalk sign. In addition, the crossing distance could be reduced from the current distance of 50 feet. Although the distance is less than 60 feet, a reduction in crossing distance would be beneficial. Instead of traffic calming, which would be infeasible at this location, a simple lateral shift of the sidewalk wheelchair ramps could shorten the crossing distance. Also, the lateral shift of the wheelchair ramps may improve the pedestrian's sight distance from the crossing looking upward to the oncoming roadway.

These treatments may seem extensive, but they are relatively simple. Two new wheelchair ramps, a marked crosswalk, and two warning signs are all that is needed.

Case 3 – Bizzell St. at New Main Dr., Texas A&M University, College Station, Texas

Situation Description

New Main Dr. is the main entrance to the Texas A&M University campus, and it forms a T-intersection with Bizzell St. Both roadways are recently reconstructed collector roadways, and Bizzell was provided with sidewalks on the east side of the roadway near this intersection. The path of the sidewalk is interrupted by the intersection, which is controlled by stop signs for all directions. On the approach to the intersection, the sidewalks on Bizzell St. curve into the sidewalks for New Main Dr. Although pedestrians cross New Main Dr. at Bizzell St. daily, no wheelchair ramps are provided, and no crosswalk provisions are made at the intersection. The annual daily traffic for New Main Dr. is over 10,000 vehicles, and the posted speed limit is 40 mph. Although the sidewalks are curved away from the intersection, the author contends that a legal crosswalk (crossing New Main Dr.) exists at this intersection.

Figure 20 displays an eastward view of the intersection looking down New Main Dr.



Figure 20. Eastward View of New Main Dr. at Bizzell St.

Figure 21 displays a southward view of the intersection from the existing sidewalk.



Figure 21. Southward View of New Main Dr. at Bizzell St.

Problems and Concerns

The problems as seen by the author are:

- Posted speed $\geq$ 40 mph; and
- High volume, multi-lane roadway.

Some concerns of the author are:

- No treatments for pedestrians to cross the street at this intersection;
- No wheelchair ramps at the crossing; and
- Pedestrians will attempt to cross the street, regardless of the lack of crossing treatments.

Improvements

The author notes only a few simple improvements for the intersection. First, the sidewalks could be extended to the roadways with wheelchair access ramps. Using the guidelines, the author noted that a standard marked crosswalk should be installed. Also, since the posted speed on New Main Dr. is 40 mph, a Pedestrian Crossing sign should be installed. These are the only improvements that the author recommends. Since the intersection is controlled by stop signs, no other treatments should be necessary.

RECOMMENDATIONS

The area of pedestrian safety will continue to be one of the most interesting and challenging for engineers and planners. This report focused on physical pedestrian safety treatments, but it omitted pedestrian signaling. Many pedestrian safety problems are at signalized intersections, and a comprehensive report examining the many pedestrian signaling improvements available would be a valuable resource. In addition, some of the treatments discussed in this report have not been extensively researched for their safety implications. Specifically, angled or channeled center refuge islands and in-pavement flashing crosswalk lights need to be researched more for quantitative pedestrian safety results.

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EVALUATION OF THE EFFECTIVENESS OF ROUNDABOUTS IN AN ARTERIAL NETWORK – A CASE STUDY USING MICRO-SIMULATION

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SUMMARY

This purpose of this research was to evaluate the effectiveness of roundabouts in an arterial network by using the micro-simulation software VISSIM. Micro-simulation allowed for comparison of the operations of the existing network corridor vs. various potential corridor alternatives.

An arterial corridor in Saratoga County, NY was analyzed to illustrate how micro-simulation can be used to evaluate alternative intersection treatments, specifically roundabouts. The author evaluated multiple scenarios along the corridor at both the existing and future traffic volumes, including:

- Existing actuated uncoordinated signal operations (40/45 mph, current volumes only);
- Existing actuated uncoordinated signal operations (30 mph, current volumes only);
- Optimized, pretimed signal operations (30 mph, current and future volumes);
- Optimized pretimed signal operations with additional thru lane (30 mph, current and future volumes); and
- Roundabouts (30 mph, current and future volumes).

The measures of effectiveness were total travel time and average delay along the corridor.

Under existing traffic conditions, the addition of roundabouts produced significantly lower travel times and delays for the network vs. the existing actuated uncoordinated signalized intersections, and were the best performing of all alternative treatments. For the projected future traffic (2024), optimized pretimed traffic signals with an added through-lane operated slightly (but not significantly) better than the roundabouts. In addition, both the optimized signals with an added through-lane and roundabouts showed considerably lower travel times and delays with 2024 traffic volumes than the existing network operations with *current* traffic volumes.

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INTRODUCTION

Although roundabouts have been widely used in other countries as an alternative for traffic signals, it is only during the past few years that roundabouts have gained popularity as a tool for traffic calming, safety and improving roadway capacity. A roundabout that operates within its capacity will generally produce lower delays than a signalized intersection operating with the same traffic volumes and right-of-way limitations (1). Roundabouts are often used to moderate traffic speeds, improve the aesthetics of the roadway, and are cheaper to operate than traffic signals.

Although not part of the analysis performed in this study, roundabouts are also known to promote the reduction of certain types of severe intersection-related collisions, such as right angle or head-on collisions (2,3). This is due to the geometric configuration of roundabouts. As a result, the collisions that do occur at roundabouts often are sideswipes or rear-end accidents, which produce fewer injuries than the more severe types of intersection collisions.

With the increased interest in roundabouts, it is of value for traffic engineers to understand the effect that the roundabouts will have on network traffic operations prior to their construction. Traffic simulation software is commonly used to assess traffic operations along roadway networks, including those with roundabout intersections. After reviewing the literature, it was determined that VISSIM was the best simulation tool due to its excellent graphical capabilities and its ability to model roundabouts through user defined parameters. In the VISSIM program, the user has the ability to control headway and gap acceptance. For vehicles entering and exiting a roundabout, smaller gap acceptances are common because traffic is yielding rather than stopping. Unlike other micro-simulation programs, VISSIM allows the analyst to modify gap acceptance criteria allowing for a more accurate representation of roundabout operations. VISSIM has considerable flexibility and is a widely recognized tool for simulating unique operational characteristics.

This purpose of this research was to evaluate the effectiveness of roundabouts in an arterial network by using the micro-simulation software VISSIM. It was hypothesized that the addition of roundabouts to the corridor would reduce average operating speeds and decrease total delay for the corridor. The author used VISSIM to compare the traffic operations for the corridor after the addition of the proposed roundabouts versus the existing signalized intersections and other non-roundabout alternatives described in the following subsection.

Research Objectives

Simulations were used to analyze the performance of five sequential roundabouts and five signalized intersections. Several objectives were established in order to achieve this goal. The research objectives were to simulate the:

- Existing actuated uncoordinated signal operations (40/45 mph);
- Existing actuated uncoordinated signal operations (30 mph);
- Optimized, pretimed signal operations (30 mph, current and future volumes);
- Optimized pretimed signal operations with additional thru lane (30 mph, current and future volumes); and
- Roundabouts (30 mph, current and future volumes).

The five objectives led to the development of seven alternative simulations. Five simulation runs of each corridor alternative were created. Other objectives included compare the characteristics of each design and determining if the roundabouts could accommodate the increased traffic volumes for the 20 year forecast.

Scope

The purpose of the research was to evaluate the effectiveness of replacing signalized intersections on an arterial corridor with roundabouts. The analysis consisted of simulating a single case study from Saratoga County, NY in which five signalized intersections on an arterial were replaced with modern roundabouts.

LITERATURE REVIEW

Roundabouts

The term modern roundabout is used to differentiate it from the nonconforming traffic circles or rotaries that have been used for many years. A modern roundabout is defined by two basic operational and design principles: yield at entry, and deflection for entering traffic. Yield-at-entry is the most important operational element of a modern roundabout. It requires that vehicles in the circulatory roadway have the right-of-way and all vehicles on the approaches have to wait for a gap in the circulating flow (4). Modern roundabouts have deflection for the entering traffic usually in the form of splitter islands at entry and a raised central island. Deflection results in lower speeds and improved safety for roundabouts.

Many modern roundabouts have successfully been built throughout the world, particularly in Europe and Australia since the 1950s. Over the last few years in the United States, modern roundabouts have become a subject of great interest. This interest is partially a result of reported good performance of existing roundabouts and acceptance by the public. The Federal Highway Administration (FHWA) estimates that over 50,000 roundabouts will be built in the next decade (4).

Modern roundabouts are beginning to be considered as an alternative traffic control device (TCD) that can improve safety and operational efficiency at intersections when compared to their conventional intersection controls. In some cases, they are being considered as a viable TCD at complex freeway interchanges and in series on arterial streets. Roundabouts in an arterial setting have been successfully implemented in Avon and Golden, Colorado. Amongst others, there are also several proposed roundabouts in series in Mississippi, Missouri, Kansas, Montana and New York.

In a recent study conducted by the National Cooperative Highway Research Program (NCHRP), the following was concluded (4):

- Total crashes decreased 37 percent and injury and injury crashes decreased 51 percent at 11 studied intersections converted to roundabouts.
- Roundabouts have significant benefits in terms of safety, capacity, reduced delay, reduce emissions and aesthetic improvements to urban design.
- Respondents to a survey of all North American state and provinces and 26 municipalities were unanimously satisfied with their roundabouts and would consider building more roundabouts in their jurisdiction.
- Delays in US roundabouts are about 75% less than under the previous traffic control method.

Simulation

Traffic simulation can be used to assess traffic operations along roadway networks. There are five microscopic models commercially available: CORSIM, AIMSIM, Paramics, and VISSIM. At a macroscopic level, SIDRA and RODEL are typically used to analyze roundabouts in the United States (5).

Microscopic simulation of traffic has become a valuable aid in assessing the system performance of traffic flows and networks, as recognized by the Highway Capacity Manual (6). Microscopic simulation

tools allow for detailed analysis of traffic systems and have great potential for analyzing roundabout alternative strategies. They implicitly account for the stochastic nature of the transportation system and can provide both temporal and spatial information down to the individual vehicle level.

With the increase in traffic simulation as a tool for comparing one roadway alternative to another, one should understand the complexities in simulating the unique characteristics of roundabouts. Modeling of roundabouts in VISSIM requires the detailed coding of links, connectors, priority rules, speed zones and gap acceptance. As well, the VISSIM software package provides roundabout examples that include explicit modeling of transit and pedestrians. Thus, this program allows for more accurate roundabout simulation than other models (*1*). VISSIM has considerable flexibility and is a widely recognized tool for simulating unique operational characteristics.

CASE STUDY

A case study in Saratoga County, NY was used to illustrate the effects of roundabouts. The current corridor is a two-lane roadway with five actuated, uncoordinated signalized intersections. The speed limit is currently between 40 mph and 45 mph along the corridor. The corridor currently provides a low level of service and motorists frequently experience long delays and travel times. The New York State Department of Transportation has proposed that the speed limit be reduced to 30 mph as a measure of traffic calming to discourage speeding on the corridor. Therefore, all alternative treatments were analyzed at the 30 mph speed limit. The following alternatives were considered for this analysis:

- converting actuated, uncoordinated traffic signals to pretimed signals,
- changing actuated, uncoordinated signals to optimized¹ pretimed intersections with the addition of one additional thru lane in each direction, and
- replacing the actuated signalized intersections with roundabouts.

The proposed corridor design with roundabout intersections aligns five roundabouts in series along Route 67, including two at the diamond interchange. VISSIM simulations were performed for the numerous intersection treatment alternatives, including the existing design (coordinated signalized intersections) and the proposed design (roundabouts). The simulations were compared to determine if roundabouts provide improved travel time and decreased delay for both the existing (2004) and forecasted (2024) traffic volumes. The corridor traffic volumes used in the study can be found in the appendix A (see figures A1 and A2). Figure 1 illustrates the existing Route 67 corridor with the signalized intersections. Figure 2 illustrates a hypothetical view of the Route 67 corridor with the proposed roundabouts overlaid onto the network.



Figure 1. Existing Route 67 Corridor

¹ Signal optimization was performed using Synchro version 5.



Figure 2. Hypothetical Route 67 Corridor with Proposed Roundabouts

Table 1 presents a description of the various corridor alternatives that were analyzed.

Table 1. Description of Corridor Alternatives

Forecast Year	Scenario	Intersection Treatment				Posted Speed Limit	
		Signals			Roundabouts	40/45 mph	30 mph
		Existing Timings	Optimized Timings	Optimized Timings & Added Thru Lane			
2004	Existing	X				X	
	Alternative 1	X					X
	Alternative 2		X				X
	Alternative 3			X			X
	Alternative 4				X		X
2024	Alternative 2		X				X
	Alternative 3			X			X
	Alternative 4				X		X

RESULTS

Five simulations of each scenario were performed, each using a different random number seed. The random number seed was constant for a given replication across each of the alternatives. The random number seed was varied across replications to allow for randomization of the micro-simulation. Five travel time and delay estimates were generated for each corridor scenario. Estimates were generated for both the eastbound and westbound vehicles for the entire 4593 feet (1400 meters) of the corridor. Travel times estimates were obtained by using the travel time measurement function and the delay estimates

were acquired using the node evaluation option in VISSIM. The average travel time is determined as the time a vehicle crosses the first cross section to crossing the second cross section. Node evaluation is a way of collecting data for a user defined area within a VISSIM network (Z).

The travel time and delay estimates for each of the five replications were then weighted based on the directional traffic volume (see Equation 1 below) and averaged (see Equation 2). A summary of the micro-simulation results from the five replications for each scenario are presented in Table 2. Detailed delay and travel time results from VISSIM simulations can be found in figures B1 and B2 of Appendix B, respectively.

$$\bar{t}_{.j} = \frac{\sum_{i=1}^M t_{ij} V_{ij}}{\sum_{i=1}^M V_{ij}} \quad \forall j = 1, N \quad (\text{Equation 1})$$

where: $\bar{t}_{.j}$ = Weighted travel time for direction i and replication j ($j = 1$ to 10);

t_{ij} = Travel time in direction i for replication j ;

V_{ij} = Volume in direction i for replication j ;

M = Number of directions ($M = 2$, one for eastbound and one for westbound); and

N = Number of replications.

$$\bar{t} = \frac{1}{N} \sum_{j=1}^N \bar{t}_{.j} \quad (\text{Equation 2})$$

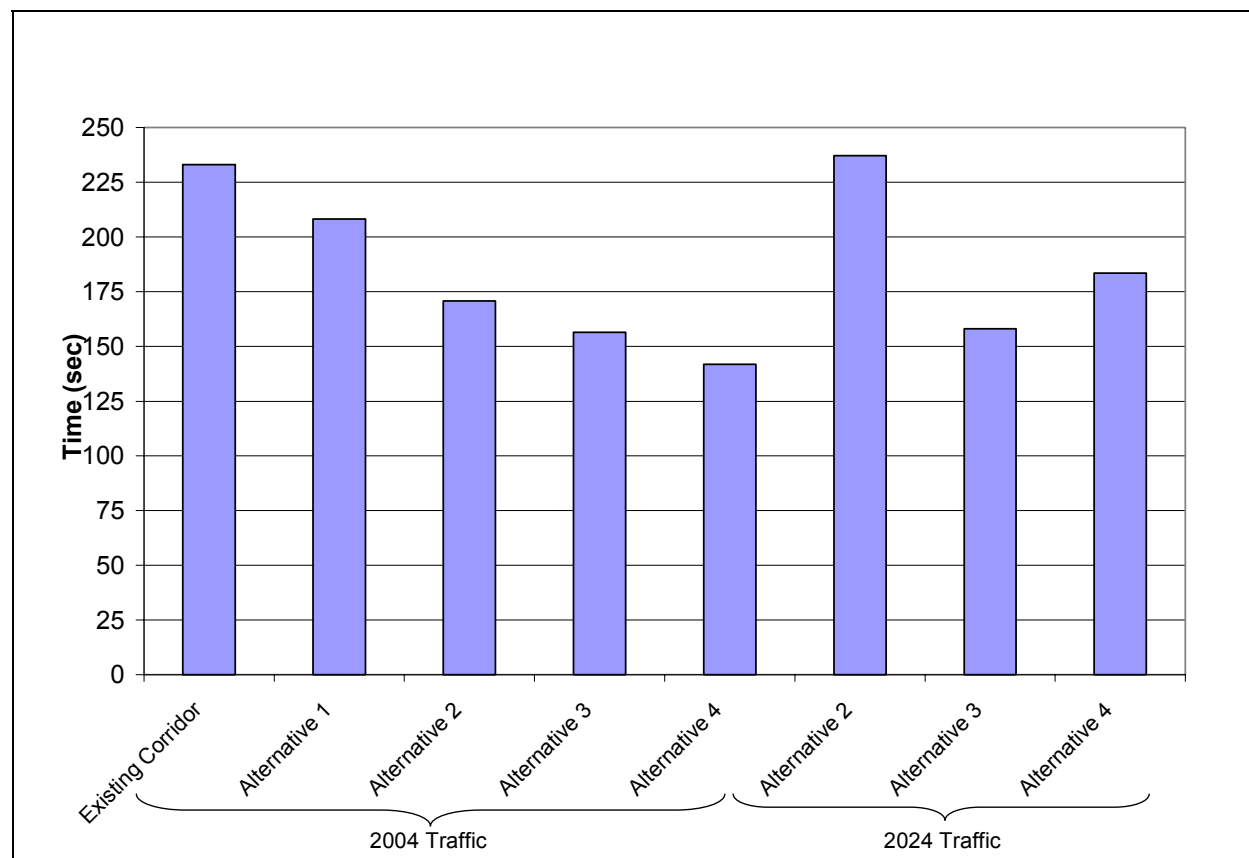
where: $\bar{t}$ = Average weighted travel time on corridor.

See Equation 1 for other variable descriptions.

It can be observed from Table 2 and Figures 2 and 3 that alternative 4 (replacing existing traffic signals with roundabouts) provides the shortest travel time and delay for 2004 traffic conditions. It can also be seen that the existing corridor simulation produced the longest delays. Roundabouts were similarly effective for 2024 traffic conditions, although alternative 3 (optimized signals with added lane) provided slightly lower travel times and delays. Statistical analyses were performed to determine if the differences displayed in Table 2 and Figures 2 and 3 were significant.

Table 2. Summary of Simulation Results

Forecast Year	Scenario	Average Travel Time (sec)	Average Delay (sec/veh)
2004	Existing Corridor	233.1	17.9
	Alternative 1	208.3	9.0
	Alternative 2	170.8	5.9
	Alternative 3	156.5	4.5
	Alternative 4	141.8	2.0
2024	Alternative 2	237.2	13.7
	Alternative 3	158.0	6.0
	Alternative 4	183.6	6.6

**Figure 2. Average Travel Time Along Route 67**

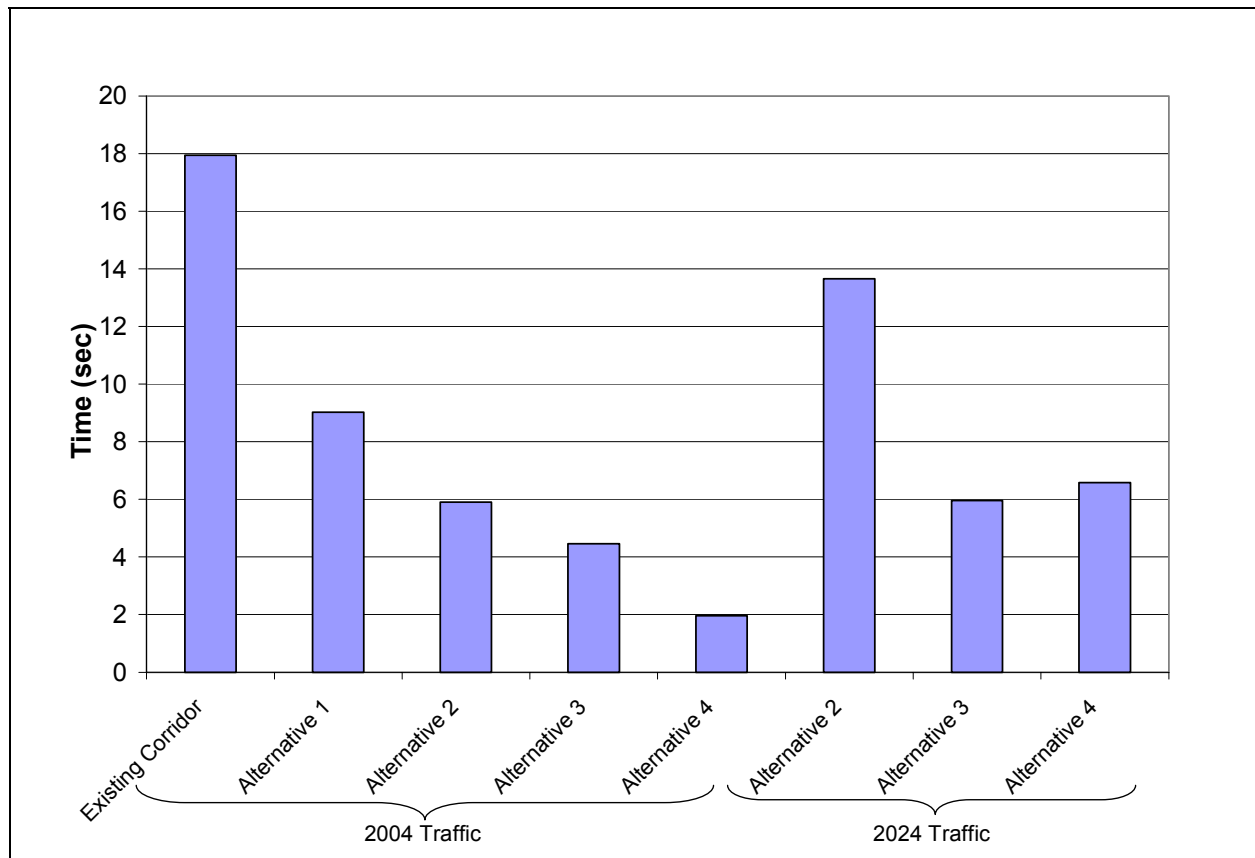


Figure 3. Average Delay Along Route 67

Results for 2004 Traffic Volumes

A one-way analysis of variance (ANOVA) was performed on the travel time and delay data to test for a statistical difference between the different scenarios at the 0.05 level of confidence using the SPSS statistical software. The null hypothesis of the test was that all scenarios are equal. Both the travel time and delay were found to have statistically significant differences between the scenarios. Therefore, the null hypothesis was rejected. Both the travel time and delay ANOVAs yielded p -values of $p < 0.0001$.

To test significant differences between specific alternatives, a subsequent Tukey studentized range test (post-hoc) was performed on both the travel time and delay results. The full results from Tukey's test and the ANOVA test are located in Appendix C (see figures C1 to C6). For the travel time analysis, alternatives 2 (optimized signals), 3 (added lane), and 4 (roundabouts) were found to outperform the existing corridor and alternative 1A. For the delay analysis, alternatives 2, 3 and 4 were also found to have significantly less delay than the existing scenario and alternative 1.

Based on the ANOVA findings for the travel time and delay, it can be concluded that the roundabouts (alternative 4) are included among the best performing corridor treatments for the 2004 traffic volumes. As expected, the existing scenario yielded the highest travel time and delay, likely due to less capacity (compared to the other alternatives) and outdated signal timings.

Results for 2024 Forecasted Traffic Volumes

The one-way ANOVA test indicated that significant differences in travel time and delay exist among alternatives 2 (optimized signals), 3 (added lane), and 4 (roundabouts). Both the 2024 travel time and delay ANOVAs yielded p-values of $p < 0.0001$. Tukey's post-hoc test shows the alternative 3 and 4 provided significantly lower travel times and delays than alternative 2. This was expected because both alternative 3 and 4 involved adding additional capacity to the roadway in the form of an added lane and roundabout, respectively.

Simulation results indicate that the average delays for the 2024 forecasted volumes are slightly higher for the roundabout scenario (alternative 4) than for the optimized scenario with an additional lane (alternative 3). This is because the roundabout for the northbound entrance ramp becomes highly congested under 2024 forecast traffic volumes. The optimized/added lane scenario may likely operate better due to the platooning of vehicles from the traffic signals, opposed to random arrival patterns generated by roundabouts.

FINDINGS AND RECOMMENDATIONS

Findings

Based on these research findings, it is expected that four of the five proposed roundabouts will have the capacity to accommodate the 2024 forecast volumes. Even with one of the roundabouts approaching capacity, the proposed corridor still operates better than most of the other alternatives. It appears that under 2024 forecasted traffic volumes, the use of modern roundabouts on the Route 67 corridor are an effective means of reducing travel time and delay across the corridor, even when the speed limits are reduced. It is the authors' opinion, based on this study, that the proposed roundabout interchange design is a valid alternative and will support the 20 year growth.

It is important to note that this model was not validated due to time constraints of the project and lack of travel time data in the field. However, based on the findings of this study, the addition of roundabouts to the arterial network appeared to decrease the overall travel time and delay along the corridor when compared to the existing conditions. The micro-simulation analysis performed here indicated that micro-simulation may be used to provide an assessment of roundabouts in an arterial network when compared to signalized intersections, but due to the lack of validation, solid conclusions cannot be drawn here pertaining to the accuracy of the findings.

Recommendations

It is recommended that the results of the VISSIM simulations performed here be validated with actual field data collected at the site. Validation of the VISSIM model for simulation of roundabouts is necessary to determine if the gap acceptance, queue length and travel speeds are realistic. Because the roundabouts have not yet been built, validation with field data was not possible for this study. Although out of the scope of this study, the results of the VISSIM model should be validated against future field data or other software packages such as CORSIM or Paramics. The model may also be validated using the delay formulas given in *Roundabouts: An Information Guide* published by FHWA ([1](#)). Future research for the Saratoga County case study might include determining when the roundabouts on Route 67 will reach capacity.

ACKNOWLEDGEMENTS

This paper was prepared for the graduate summer course Advanced Surface Transportation Systems at Texas A&M University. The author would like to extend her appreciation to her professional mentors, Tom Werner of the New York State Department of Transportation for his continued guidance and support throughout the development of this paper. In addition, the author would like to recognize the other professional mentors who contributed to this course and paper, including Marsha Anderson Bomar, Walter Kraft, Wayne Shackleford, Gary Trietsch, and James Wright. Dr. Conrad Dudek organized and directed the course.

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APPENDIX A – TRAFFIC VOLUMES

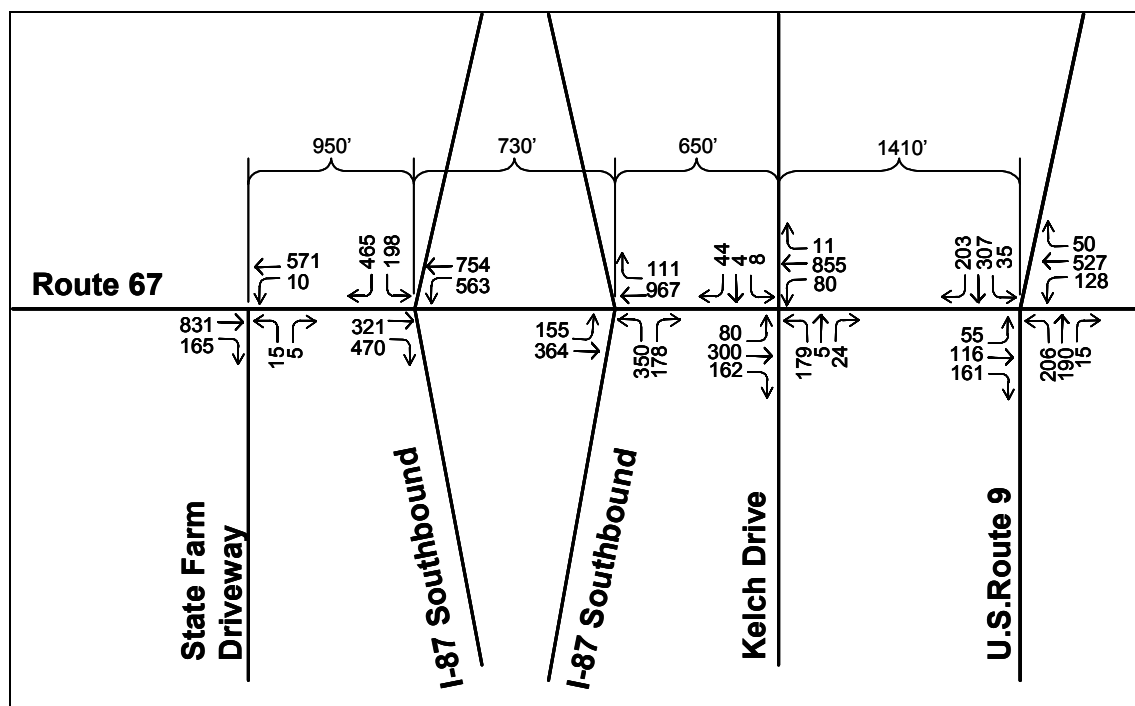


Figure A1. 2004 AM Peak Hour Traffic Volumes

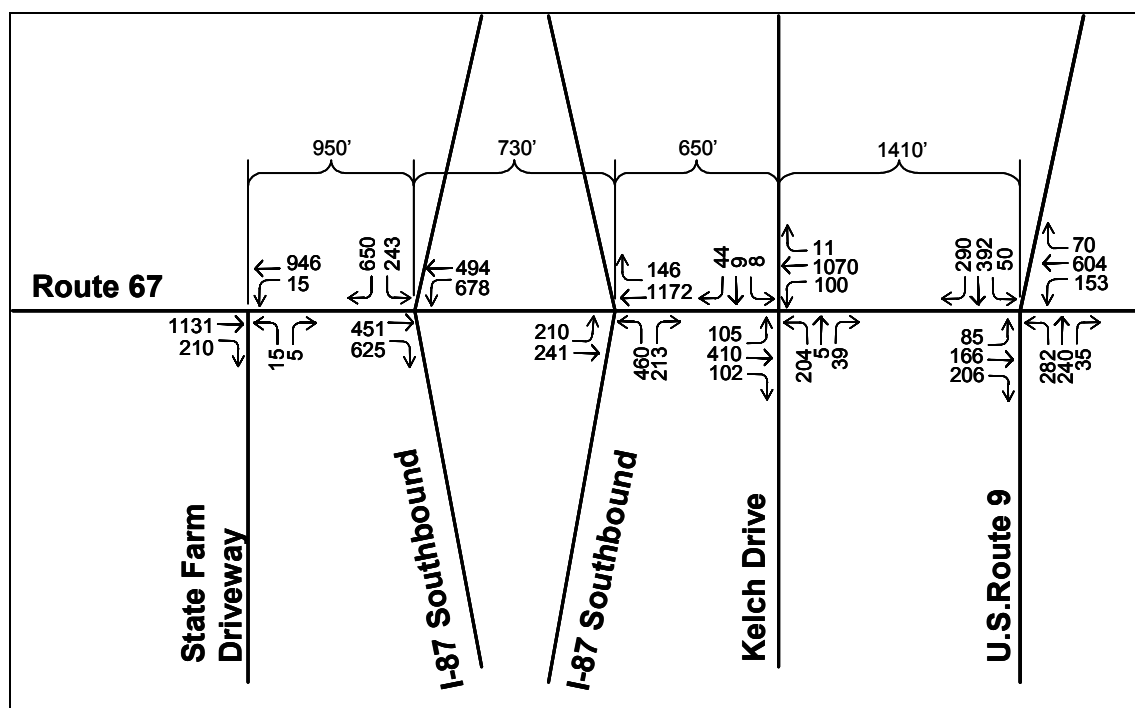


Figure A2. 2024 AM Peak Hour Traffic Volumes

APPENDIX B – Micro-simulation Results**Table B1. Micro-simulation Delay Results**

			Delay per Vehicle (sec)				
			Simulation Number				
Scenario	Alternative	Forecast Year	1	2	3	4	5
Existing Signal Operations	Existing Corridor	2024	10.8	25.9	20.2	16.7	16.1
Existing Signal Operations	Alternative 1		9.7	9.7	8.0	10.4	7.3
Optimized Signal Operations	Alternative 2		6.6	5.8	5.2	5.5	6.4
Optimized Signal Operations with Additional thru Lane	Alternative 3		4.4	4.4	4.4	4.5	4.6
Roundabouts	Alternative 4		1.8	2.1	1.9	2.0	2.0
Optimized Signal Operations	Alternative 2	2024	13.2	13.7	14.5	12.8	14.1
Optimized Signal Operations with Additional thru Lane	Alternative 3		5.4	6.1	5.9	6.6	5.8
Roundabouts	Alternative 4		8.1	5.6	5.4	7.4	6.4

Table B2. Micro-simulation Travel Time Results

			Travel Time (sec)				
			Simulation				
Scenario	Alternative	Forecast Year	1	2	3	4	5
Existing Signal Operations	Existing Corridor	2004	191.0	282.7	239.1	244.1	208.5
Existing Signal Operations	Alternative 1A		215.7	216.8	197.4	215.7	195.7
Optimized Signal Operations	Alternative 2A		168.8	166.3	170.5	175.5	172.7
Optimized Signal Operations with Additional thru Lane	Alternative 3A		155.7	151.2	158.8	158.9	157.8
Roundabouts	Alternative 4A		139.4	141.9	141.1	143.5	143.4
Optimized Signal Operations	Alternative 2B	2024	230.3	237.1	236.4	237.0	245.4
Optimized Signal Operations with Additional thru Lane	Alternative 3B		155.0	159.2	161.0	158.2	156.6
Roundabouts	Alternative 4B		201.1	172.8	171.2	188.9	183.9

APPENDIX C – STATISTICAL RESULTS

Analysis of Variance

Table C1. Delay Results for 2004 Traffic Volumes

Measure of Effectiveness		Sum of Squares	Degrees of Freedom	Mean Square	F-value	Significance
Delay (sec)	Between Groups	765.82	4	191.45	28.86	4.70E-08
	Within Groups	132.68	20	6.63		
	Total	898.50	24			

Table C2. Travel Time Results for 2004 Traffic Volumes

Measure of Effectiveness		Sum of Squares	Degrees of Freedom	Mean Square	F-value	Significance
Total Travel Time (sec)	Between Groups	28437.71	4	7109.43	25.59	1.27E-07
	Within Groups	5557.25	20	277.86		
	Total	33994.97	24			

Table C3. Delay Results for 2024 Traffic Volumes

Measure of Effectiveness		Sum of Squares	Degrees of Freedom	Mean Square	F-value	Significance
Delay (sec)	Between Groups	183.00	2.00	91.50	137.39	0.00
	Within Groups	7.99	12.00	0.67		
	Total	190.99	14.00			

Table C4. Travel Time Results for 2024 Traffic Volumes

Measure of Effectiveness		Sum of Squares	Degrees of Freedom	Mean Square	F-value	Significance
Total Travel Time (sec)	Between Groups	16354.52	2	8177.26	132.28	6.67E-09
	Within Groups	741.80	12	61.82		
	Total	17096.32	14			

Tukey Test**Table C5. Delay Results for 2004 Traffic Volumes**

Corridor Scenario	N	Subset for alpha = .05		
		1	2	3
Alternative 4	5	1.96		
Alternative 3	5	4.46	4.46	
Alternative 2	5	5.90	5.90	
Alternative 1	5		9.02	
Existing Corridor	5			17.94
Significance		0.15	0.07	1.00

Table C6. Delay Results for 2024 Traffic Volumes

Corridor Scenario	N	Subset for alpha = .05	
		1	2
Alternative 3	5	5.96	
Alternative 4	5	6.58	
Alternative 2	5		13.66
Significance		0.47	1.00

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Kristin has gained experience by working at various well-known companies. Kristin is currently employed with the Texas Transportation Institute (TTI) as a Graduate Research Assistant. Her work has primarily included using the micro-simulation software VISSIM for evaluating access management treatments. Prior to joining TTI, she was employed at Hubbell, Roth and Clark, Inc. (HRC), a consulting firm in Bloomfield Hills, MI for four summers. While at HRC, Kristin performed duties including surveying, engineering road design, and construction inspection of the installation of watermain, sewer and concrete road paving. While at MSU, she worked for the City of East Lansing Department of Public Works – Engineering Division for one semester. Her projects were related to the redesign and reconditioning of city roadways. She also worked at the Michigan State University Physical Plant as an Engineering Intern for one semester where she performed utility markings, land surveying and AutoCAD drafting.

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SECURITY OF INTERMODAL CONTAINER FREIGHT AND APPLICATIONS OF ITS AT PORT FACILITIES

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SUMMARY

The volume of intermodal container freight coming into the United States is growing significantly. With this increasing volume comes great benefit; however, it also brings great concern for security of containers at port facilities. There is a need for intermodal container security devices that can provide higher levels of security without impairing the effectiveness of operations at port facilities. Several devices are being developed and implemented throughout national and foreign port facilities that utilize intelligent transportation system (ITS) technologies to provide a higher level of security and maintain an efficient flow of containerized goods through the port facilities.

To determine the extent of container security device use in the United States, a survey of state Port Authorities was conducted. The results of the survey indicated that ITS capable devices are being explored and will be prevalent in future security systems in national and international port facilities. The survey results also indicated that these security devices were still being researched and would be more widely used once political mandates were established and accepted.

Based on the research, five techniques were determined to be applicable to address the problem of intermodal container security. The five devices include the following:

- Electronic cargo seals;
- Electronic manifests;
- Container code reading systems;
- X-ray inspection systems; and
- Gamma ray inspection systems.

The devices were designed and developed to provide high levels of security without compromising the efficiency of transporting container freight at port facilities. To do so, ITS technology was implemented to support a multi-layered security system that could be monitored by shipping companies and government inspection agencies. The five devices include the following capabilities:

- Track-and-trace procedures;
- Communication abilities between multiple entities;
- Accurate levels of material identification; and
- Quick and accurate data dissemination abilities.

The five devices were applied to a theoretical case study container to determine effectiveness and to provide a map of how best to implement and utilize these technologies. The results indicated that with the implementation such devices would allow for a free flowing system of information among various transportation and government agencies, real-time tracking of containers, and the capability of quickly and accurately detecting high-risk containers from the time it is loaded until the time it reaches the final destination. The results also indicated that the devices provided the aforementioned abilities without compromising the operation efforts at the port facility.

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INTRODUCTION

The volume of intermodal freight is growing significantly. This growth can be seen from the boom of marine, rail, air, and truck intermodal operations. These transportation modes have utilized a standard intermodal container for the purpose of transporting goods. The volume of these intermodal containers moving through United States ports has increased substantially over the past decade (1).

To accommodate the rapid growth, the intermodal freight industry and state Departments of Transportation (DOTs) must work with port facilities to continue to improve operations and maintain high levels of efficiency and reliability. There is currently a shift in terms of global movement of freight. The infrastructure that supports the movement of containerized freight has been developed and constructed to enhance efficiency and reliability. However, the intermodal transportation industry has been aware that its infrastructure is vulnerable to security breaches. In the aftermath of the terrorist attacks on September 11, 2001 in New York City and Washington D.C., freight security challenges has been at the top of the priority list within intermodal transportation, especially at port facilities (1).

Problem Statement

Intermodal container freight has a significant impact on the state of the world economy. A disruption in the end-to-end operations of this system could be considerable. The problem that faces engineers, researchers, and scientists today is to provide technologies that enhance the security of intermodal transportation without jeopardizing the efficiencies of transportation operations. To combat these concerns, the United States Customs Service has launched two programs to promote security within the intermodal transportation system: the Customs-Trade Partnership Against Terrorism and the Container Security Initiative (2). There is a need today to supplement these technologies with intelligent transportation systems (ITS) to increase their effectiveness and enhance reliability of port facilities.

Research Objectives

The primary objectives of this research were to:

1. Identify vulnerabilities for security breaches at national and international port facilities;
2. Identify state of practice security devices for containerized freight to enhance security and maintain operation efficiency;
3. Project the future of containerized freight security devices based on international practices;
4. Develop applications of ITS technologies to supplement and support security devices;
5. Identify effects of economic competitiveness at national port facilities with implementation of ITS technologies; and
6. Apply the results of the research to a case study in a United States port facility.

THE NEED FOR CONTAINERIZED SECURITY DEVICES

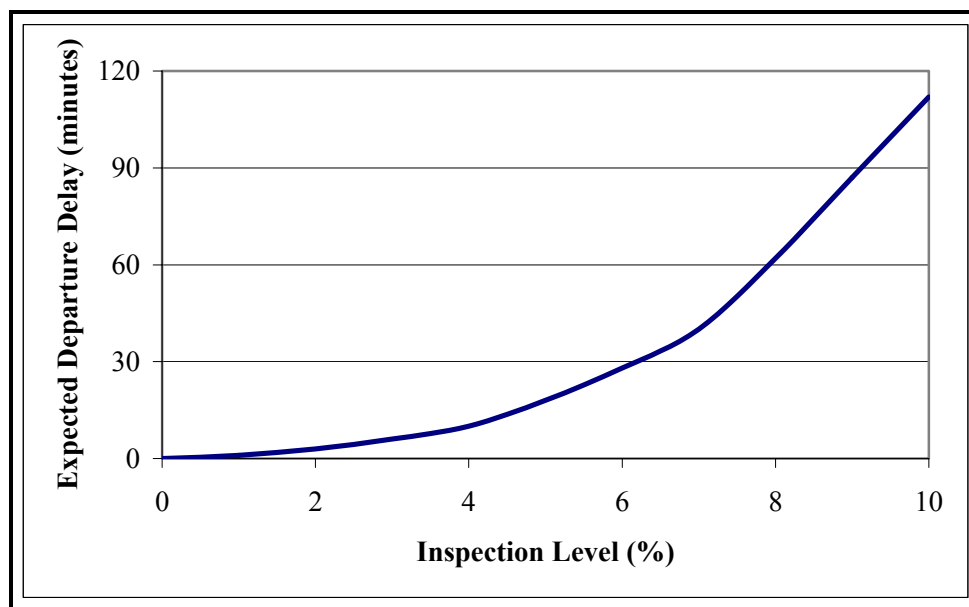
The world economy is predicated on a transportation system that works efficiently and securely to carry out the exportation of goods, an industry that accounted for \$6.186 trillion in 2001 (3). The bulk of these exports are carried in intermodal containers. Nearly 80 percent of goods are transported in intermodal containers (4). The United States, who is the world's leading exporter and importer of containerized freight, has seen the volume increase steadily in the past ten years. The emphasis on world trade and containerized freight has translated into container traffic coming into the United States that ranges from 18,685,707 twenty-foot-equivalent units (TEUs) in 1992 to 35,668,133 TEUs in 2002, as shown in Table 1. This influx in growth has put strains on operation efficiencies at port facilities and also given more opportunity for security breaches at those facilities (5).

Table 1. Container Traffic in U.S. Port Facilities (5)

Coast	Container Traffic in TEUs			Percent Increase (1992 to 2002)
	2002	1997	1992	
U.S. Pacific Coast Ports	17,363,500	12,086,670	8,903,896	95%
U.S. Atlantic Coast Ports	13,274,747	10,945,552	7,212,311	84%
U.S. Gulf Coast Ports	1,730,218	1,517,530	1,190,283	45%
U.S. Total Ports	32,368,465	24,549,752	17,306,490	87%

In a statement to a Senate Committee on Government Affairs, Senator Joseph Lieberman stated: “It is not possible to physically inspect more than a small sample of containers as they arrive in the U.S. Less than one percent are actually examined, and that leaves our ports, unfortunately vulnerable to attacks (6).” The tremendous flow of goods creates many kinds of vulnerabilities in the port facilities. Smuggling of drugs and illegal aliens are a major concern; however, those types of breaches take a backseat in the “Post 9/11” world to the exploitation of the port facilities by terrorist organizations. A major concern of these vulnerabilities is the fact that many U.S. and international ports are located in or near major metropolitan areas, where a break in security could have catastrophic consequences (6).

The increased security checks and inspections have resulted in decreases in port operation efficiencies. Slowing the flow of goods long enough to inspect only a statistically significant random selection of imports would be economically intolerable (6). The inspection level of a shipment of containers has a profound effect on the amount of delay that is experienced. An illustration of this cause-and-effect relationship is shown in Figure 1 (4).

**Figure 1. Relationship of Inspection Level of Containers and Delay (4)**

In reviewing these statements and statistics, the need for devices to increase security at port facilities while maintaining an efficient level of operation becomes clear. To support these security devices, there is a need for ITS technology for data management, tracking of containers, and incident management purposes. It is anticipated that implementation of such security devices with ITS capabilities will not only maintain security and efficient operation levels, but also give an economic edge to the port facility.

BACKGROUND OF CONTAINER SECURITY DEVICES AND ITS TECHNOLOGY

Container security devices have been the focus of improving security at port facilities. The types of devices that have been developed include electronic cargo seals, electronic manifests, container code reading systems, x-ray inspection systems, and gamma-ray inspection systems. A brief background and inclusion of each device and ITS technology for these devices is presented in this section.

Electronic Cargo Seals

Electronic cargo seals (E-Seals) are intelligent cargo seals that can automatically alert dispatchers via wireless communication if tampering or vandalism occurs. E-Seals, which are about the size of a deck of cards, consist of a bolt that locks the container when inserted into the seal body and serves as an antenna. The seal body contains a computer chip for information encryption and a battery for transmitting information that is queried by the reader. Information such as date, time, and location (longitude and latitude) of the container can be transmitted (Z, 8).

There are three widely used types of electronic seals. Each type utilizes different ITS communication technology to transmit data from the container seal to the port authority's "reader." The three types of communication technology include radio frequency identification (RFID), direct contact, and long range cellular or satellite communication.

Radio Frequency Identification

RFID technologies are most common among electronic seals. The two types of RFID seals are passive and active. Passive RFID seals respond to interrogation by the reader to report identification and to perform processes such as integrity checks of the seal. Active seals can also initiate communication with the reader to notify the reader of status and submit live "mayday" reports in events of tampering (9).

Direct Contact Seals

Some of the seals operate in conjunction with another device to provide power for data management and to carry out processes dictated by the reader. Some of the add-ons to the E-Seals include contact memory buttons, personal data assistants (PDAs), and electronic key plug-ins. This communication technique involves a human element to be more prevalent in the monitoring process, which is argued to be both beneficial and a hindrance to the operation process (9).

Remote Reporting Seals

A small number of E-Seals utilize satellite or cellular communication techniques. The major advantage to this communication link is real-time ITS data and the ability to maintain visibility en route with the container. However, these communication links are highly expensive and thus, the least used devices (9).

A comparison of each of the technologies and concerns with each type of E-Seal is shown in Table 2.

Table 2. Comparisons of E-Seal Technologies (2)

E-Seal Technology	Positives	Concerns
RFID	• Broad array of capabilities • Passive can be very low cost • Active can be high capability and moderate cost • Can take person out of the inspection loop • Movement on standards	• Lack of standards, but this is being addressed • Lack of global frequencies, especially in regard to active RFID
Direct Contact	• Some are highly reliable in harsh environments • Demands human involvement in seal inspection	• Contact "keys" subject to loss and misuse • Demands human involvement in seal inspection
Remote Reporting	• Potential for immediate identification of problems • Potential for global coverage	• High cost • Usually requires significant outbound power
All	• Potential to improve efficiency along with security	• Risks of increasing complexity, opening new avenues of attack, and generating false confidence • Need for independent assessment of vendor claims • Need to assess operational impacts as well as technical performance • Requirement to manage and sift increased data flow, identify false positives, and act on true positives

The goal of the E-Seals is to provide port authorities with real-time ITS data as to the location of the container and its integrity. This tool can be utilized to identify what containers are high risk and should be inspected upon arrival to the port facility.

Electronic Manifests

Electronic manifests (ESCM) have been successfully tested in airports and are being investigated as to the applicability to maritime operations for container and bulk cargo. The electronic submission of key

manifest data from the appropriate supply chain entities can be of great benefit in targeting containers for inspection. By transmitting manifest data quickly, accurately, and cheaply, containers can be targeted for inspection with minimal disruption to operations (1).

The manufacturer initiates the process of shipment by logging onto the system via biometric fingerprint readers. The completed manifest is entered onto a central server, which sends the manifest to all authorized supply chain partners (e.g. ports, shipping companies, trucking companies, etc.). The manifests are stored on the server database and whenever an event occurs involving a container, the downstream participants are notified electronically (10).



Figure 2. Biometric Fingerprint Identification Technology (11)

The ITS technology implemented with the electronic manifests allow for a higher level of security with the shipment of containers by notifying downstream participants in advance of cargo details. The advance notice will allow ports to more effectively deploy personnel and resources to determine which containers are to be inspected upon arrival. The ESCM system, which includes biometric fingerprint readers, smart cards, and Internet encryption software, will allow ports to (10, 11):

- Securely and effectively transfer container data throughout the supply chain;
- Identify and validate authorized personnel; and
- Automatically track container location and acceptance.

Container Code Reading Systems

License Plate Reader (LPR) systems, which are prevalent at toll road and high occupancy vehicle facilities, have been implemented at port facilities for automated recognition of container codes. LPR systems operate by capturing an image of each vehicle as it passes through a particular lane. The system recognizes the license plate characters from the captured image and communicates results to a host computer or locally stores the results for later use. This technology is applicable to port facilities in not only scanning entering and exiting vehicles, but also intermodal containers that are imported to and exported from port facilities (12).

The initial task of the system is to locate, isolate, and identify each of the character fields that identify intermodal containers. Once the fields are located, the images in these regions are enhanced and the

characters are isolated from the background. Each intermodal container has a unique identity code that is a combination of five character fields. The five fields and their descriptions are presented in Table 3 (12).

Table 3. Container Code Fields and Descriptions

Container Field	Requirement	Description
Owner Code	Mandatory	4 Letters (specific code; 4 th letter always 'U')
Serial Number	Mandatory	6 Numerals
Check Digit	Mandatory	1 Numeral in Box (calculated)
Country Code	Optional	2 Letters (specific code)
Size and Type	Optional	4 Numerals (specific code)

The owner code, which is assigned by the International Container Bureau in Paris, France, can be crosschecked against a list of valid codes from a database. The owner code can also be verified against the country, size, and type codes. The owner code and serial number are used in conjunction to calculate the check digit. All of the redundancies in place help to ensure a high level of confidence in the correct identification of the intermodal containers (12).

The images of the containers are sent along with the ASCII text strings to the facilities shipyard control computer system. The interfacing with the facility system allows for secure and efficient container tracking for both the port facility and shipping entity. Electronic date and time stamps allow for easy tracking of containers. The code bar checking system allows for identification of high-risk containers that can be checked and narrows the physical inspection process (12).



Figure 3. Rear View of Truck Entering Container Code Reader System (13)

X-Ray Inspection Systems

The most common form of passive inspection technology used today is x-ray based technology. X-ray devices operate by detecting differences in material densities in order to produce an image of container contents. The illegal (or hazardous) items are detected by the system operator who visually, with aid from software packages, inspects the x-ray images of the containers for contraband (14). The purposes of these systems are to (15):

- Detect and seize dangerous prohibited items such as illegal weapons, explosives, drugs, and other contraband;
- Ensure that all cargoes comply with all relevant customs regulations, including manifest verification and collection of custom's duties; and
- Deter would-be terrorists and criminals from seeking to smuggle such prohibited items or violate customs regulations.

X-Ray System Technologies and Advances

Dual Protection Beams. By using single beam or single energy systems, operators would not be able to distinguish materials accurately. However, by using dual projection beams, the probability of detection is significantly higher. The items that cannot be seen in one view can be identified in a second view. An illustration of the dual projection beam technology is shown in Figure 4 (16).

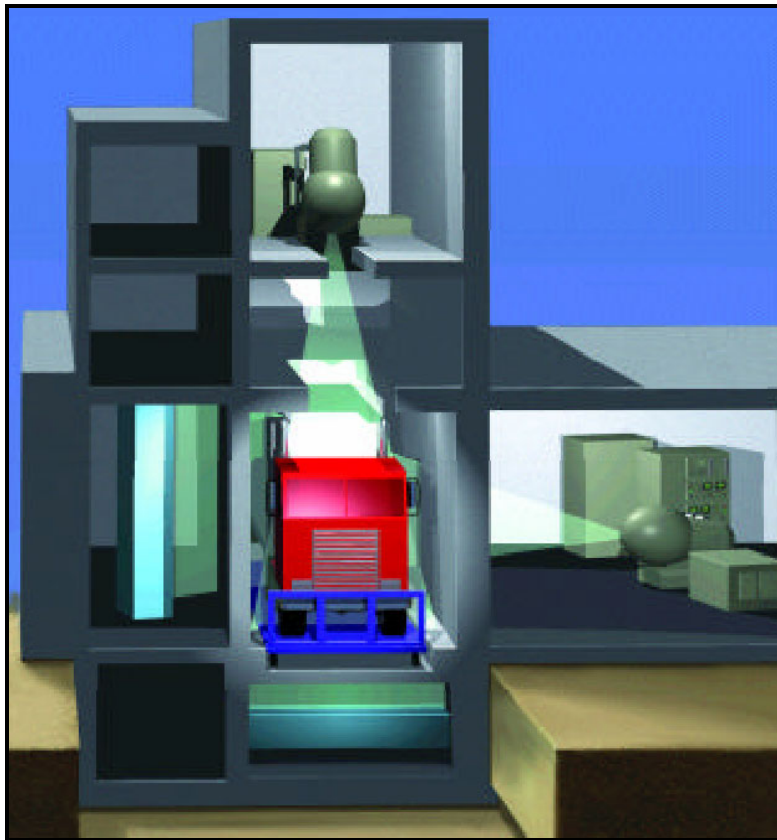


Figure 4. Conceptual Layout of X-Ray Inspection Facility (15)

Dual-Spectra X-Rays. The utilization of dual-spectra x-rays has built upon the dual beam technology by employing two beams of x-rays that peak at different energies, and thus, produces two images. By comparing the images in conjunction with sophisticated computer algorithms, information as to the effective atomic number (the number of protons in the atom's nucleus) and mass density can be determined to differentiate between materials within a container. Once the effective atomic number and mass density are determined, these results can be compared with known combinations of these parameters to detect and identify drugs, explosives, and other contraband materials. The contents of the container can also be compared to the manifest data to ensure the contents of the container have not been breached (16).

High Energy X-Rays. To penetrate cargo containers and their contents, the energy of x-rays must be higher. The technology to fully penetrate cargo containers is still being developed as well as the radiation shields to supplement the high-energy x-ray devices. These state-of-the-art x-ray detectors will provide more precise data and detailed images (16).

ITS Applications

The utilization of ITS technology in combination with the x-ray inspection systems will allow for off-site monitoring on a real-time basis. ITS technology will provide vital information on contraband, illegal weapons, and/or smuggling activities at port facilities so that should a situation dictate, response teams can be deployed to the site and transportation entities can be informed. These data management networks can also record data and images for off-line, non-real-time analysis at National or Regional Operation Centers (15).

Inspectors, representing both security and customs areas, are able to concentrate on real-time examination of containers at remote sites. The operators at the remote sites are able to use the real-time screening images to confirm the contents of the containers listed on the electronic cargo manifests (15). An inspection system at a Middle East port facility is shown in Figure 5.



Figure 5. Inspection System at Middle East Port Facility (17)

Gamma-Ray Inspection Systems

As an alternative to x-ray inspection systems, gamma-ray inspections systems were developed using pulsed fast neutrons to generate images of container contents and three-dimensional mappings of content location. Some gamma-ray systems are able to determine certain types of materials located within the container cargo. Gamma-ray systems can be in the form of fixed-site, semi-fixed-site, and mobile units. A description of the technology, configuration, and ITS applications for gamma-ray inspection systems is provided in this section ([14](#), [18](#)).

Gamma-Ray Technology

Pulsed Fast Neutron Analysis (PFNA) produces a complete digital image of the contents by exposing them to short bursts of fast sub-atomic particles called neutrons. The fast neutrons and elemental contents of the cargo interact to produce a signal that is unique to that element. The energy and quantity of signals produced by this interaction enable the system to place an elemental signature and quantity on the cargo. The time of arrival of the signals aid in determining the location of the elements within the container ([18](#)).

The technology of PFNA has been packaged in an integrated device for inspecting cargo containers. The system utilizes libraries of signatures to produce material specific images of the container contents. The libraries are an integral part of the system databases can be updated continually to include signatures of new contraband or hazardous cargoes. Another key aspect to the system is that it allows for the use of high speed processing technology to present results of the inspection to the operator. This is a contrast to the x-ray systems in that the operator must examine the images to determine if the container contains items that are breaches in security ([18](#)).

Upon completion of the inspection, the system automatically alerts the operator to any concealed contraband upon the identification of the material from the pull down menu. The location of the hazardous or illegal material is shown in a three-dimensional wire frame model of the container as shown in Figure 6. The other contents of the container are made invisible. The system allows for manipulation of the wire frame model so that viewing angles can be changes and the contents can be inspected thoroughly before opening the container ([18](#), [19](#)).

The gamma-ray screening technology can also be integrated with the electronic manifests databases to ensure the integrity of the container contents. The imaging capability of the inspection system is capable of performing counts on the cargo within containers. By performing crosschecking with the electronic manifests, missing items can be detected ([18](#)).

Configurations of Gamma-Ray Inspection Systems

The design of the systems is modular and has three main components: the source, the detectors, and the computer system. These components can be tailored to produce an inspection system that can be built on a number of configurations. The three main configuration types are fixed-site, semi-fixed-site, and mobile. A description of each configuration type is presented in this section ([18](#) - [20](#)).

Fixed-Site Systems. Fixed-site systems, as shown in Figure 6, are designed for inspecting large containers. Some systems require vehicles to remain stationary while the source and detectors scan the container from two-track driver trolleys. A simpler configuration of fixed-site systems is the pass-through systems. These systems allow containers to be transported through the detection area at four to five miles per hour while scanning occurs. The source and detectors are located in towers on either side of the scanning area and scan each container as it passes through the system ([19](#)).

Semi-Fixed-Site Systems. The semi-fixed systems are similar to the fixed-site systems with the difference being the portability of the system. Set-up is performed at space-allotting locations within

ports and layout is similar to the fixed-site systems. The semi-fixed systems can be transported and set-up within one or two days (19).



Figure 6. Fixed-Site Gamma-Ray Inspection Device (19)

Mobile Systems. The gamma-ray detection systems that may be best suited to the port facility environment are the mobile systems. The mobile system is designed around a standard vehicle platform that can be made operational in ten to fifteen minutes. The mobile system is capable of the same high-resolution performance and also the stationary or pass through detection screening abilities. The major advantage that mobile systems have over other gamma-ray detection systems and x-ray detection systems is the absence of the supporting infrastructure, which leaves more port real estate available for other operational uses. An example of a mobile gamma-ray inspection system is shown in Figure 7 (20).



Figure 7. Illustration of Mobile Gamma-Ray Inspection System (21)

ITS Applications

Gamma-ray inspection systems are similar to x-ray inspection systems in that off-site, real-time monitoring of container cargo can be performed via ITS communication technology. Response teams can be deployed using ITS technologies to accurate locations of not only the containers, but also the location of the contraband within the containers. ITS technology allows for integration of gamma-ray systems with electronic manifest databases for accurate and secure inspection of containers. ITS technology also allow for data management of the images and manifest data to be shared with National and Regional Operation Centers for off-line reviewing and implementation of security breach protocols (15, 18).

SURVEY OF THE USE OF CONTAINER SECURITY DEVICES

The literature review and background analysis of container security devices indicates the types of devices currently available for use in the United States are electronic cargo seals, electronic cargo manifests, x-ray inspection systems, and gamma-ray inspection systems. A state Port Authority survey was conducted by the author to verify the extent of usage of these types of devices, to confirm the research findings, and to identify additional devices being utilized within the United States. The Port Authority survey was conducted in the states of California (CA), Florida (FL), Georgia (GA), Louisiana (LA), Massachusetts (MA), New York (NY), Oregon (OR), Texas (TX), Virginia (VA), and Washington (WA).. In addition, the Freight Operations office of the Federal Highway Administration was contacted to provide input on recent developments and economic impacts of security devices and ITS technology at port facilities.

Port Authority Survey Development

The state Port Authority survey included a brief explanation of the proposed research. Following the introduction, a series of questions were presented to obtain information on current technologies in practice. The desired outcome of the survey was to obtain information on the following:

- State-of-the-practice container security device technology being used in each state surveyed;
- Implementation of ITS technology;
- Benefits to operations as a result of ITS technology;
- Benefits to economic competitiveness as a result of security devices and ITS technologies; and
- General thoughts on the future of the technology.

The survey was e-mailed to representatives in each of the Port Authorities outlined for a total of 10 surveys. Following the initial e-mailing of the survey, follow-up e-mail and telephone calls were placed to the respondents in order to gain input or to gain clarification on initial responses. Completed surveys were received from 7 of the 10 respondents contacted and the information was compiled for use in this study. A copy of the e-mail survey can be found in Appendix A with a summary of the survey results provided in the following section. The responding states to the Port Authority survey are highlighted in Figure 8. The specific port facilities discussed in the survey response are shown in Table 4.

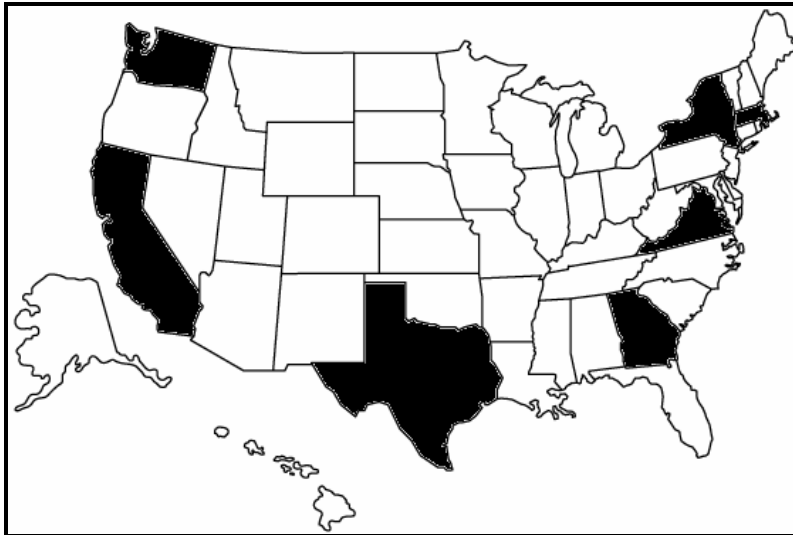


Figure 8. State Port Authority Survey Response Locations

Table 4. Ports Authorities Responding to Survey and Specific Ports Surveyed

Port Authority	Port
California	Long Beach
Georgia	Savannah
Massachusetts	Boston
New York	New York/New Jersey
Texas	Houston
Washington	Seattle
Washington D.C.	Federal Highway Administration

Port Authority Survey Results

A summary of the state Port Authority survey responses is provided in Table 5, with more detailed survey results summarized in the following sections.

The results from the survey indicated that the majority of container security devices currently in use in the United States are VACIS X-ray inspection systems, electronic cargo manifests, metal container seals, and gamma ray inspection systems.

All of the respondents indicated that a greater number of containers entering the port facility each day could be inspected with the ITS capable security devices. Survey respondents expected that the

developing technologies for container security devices would continue this trend and have a positive outcome on port operations. Reggie Sykes, Georgia Port Authority, Port of Savannah, indicated the current and developing technologies have been and would continue to be beneficial in identifying high-risk containers and monitor containers being imported from areas of high terrorist risk (22).

Table 5. State Port Authority Container Security Devices Survey Summary of Results

Question	Response
Types of Current Devices	Low Tech Seals, VACIS X-ray Systems, Electronic Cargo Manifests, Gamma Ray Systems
Current Use of ITS	Communications for electronic cargo manifest systems, and some track-and-trace capabilities
Effect on Port Operations	Improved ability to identify high-risk containers and increase in number of containers inspected
Improved Economic Competitiveness	Security devices will play an important marketing tool, shipping companies will want to contract with CSI and CT-PAT compliant ports and want faster, more secure service
Future Devices	Biometrics, Credentialing Programs, Electronic Seals, Radiation Detectors, and Nuclear Devices

The respondents seem to also indicate that implementation of devices would present additional business opportunities for port facilities. Shipping companies are being forced to become compliant with Container Security Initiative (CSI) and Customs-Trade Partnership Against Terrorism (C-TPAT) regulations, and thus, shipping companies would prefer to use port facilities that are also compliant with government regulations in terms of security infrastructure. A decision to use one port or another port relies heavily on the trade lanes coming into and leaving the port; however, shipping companies will also weigh the decision on whether the port employs up-to-date security devices for not only high levels of security, but also for rapid movement of goods through the facility and onto downstream transportation. It is believed that ports will use security devices as a marketing tool to attract business from shippers and gain an economic edge over other facilities.

The process of implementation of security infrastructure of such security devices has been slow. One of the reasons is that the technology is being tested and developed to reduce “false” positive identification. A higher reliability of devices is needed before a widespread use is seen at port facilities. Also, port facilities are awaiting policy decisions regarding requirements of intermodal security devices. Port Authorities are taking a wait-and-see stance until federal mandates are released to see what will be required of shipping companies before capital is spent on additional security infrastructure.

The developing ITS technology will be important in future security devices. The one feature that is most appealing is the track-and-trace or GPS capabilities of devices. This capability will not only allow for real-time monitoring of containers, but also be instrumental in identifying high-risk containers. The identification of high-risk containers is a major goal of port facilities because of the benefits to port operations.

When asked about future container security devices, most respondents indicated that electronic cargo seals appear to be the next big step. Jeff Davis, Manager of Barbour's Cut Terminal, Houston Port Authority indicated that biometric technology was an emerging technology that would provide security of containers while at the same time improve operations by cutting the identification process that truckers must go through to enter the port facility (23). Some other devices that were noted as future security devices were radiation detectors, nuclear devices, and credentialing programs.

INTERNATIONAL PRACTICES

The national ports are not the only ports of concern for the United States. The United States has recently expanded its Container Security Initiative to include international ports as well. The goal is to inspect "high risk" containers before they are placed on ships bound for the United States. Intelligence agencies have reported that Al Qaeda has repeatedly used containers to move weapons and explosives. The growing concern is that terrorist groups will try to use containerized freight to move chemical, biological, and/or nuclear weapons (24).

To combat the security issues at both national and international ports, technologies employed by the Port of Singapore Authority (PSA) have been investigated. The port of Singapore is the world's second largest container port in the world. Singapore is also one of the larger exporters to the United States of containerized freight. The PSA has developed a container management tool, PORTNET, to electronically link the entire shipping community. The PSA requires users (shipping lines, trucking companies, and freight handlers) to submit all required information electronically through the system. The data management tool not only allows more efficient container handling operations, but also more security of container freight (25).

Background of PORTNET

PORTNET was developed in 1984 for use in port management on export and import cargo within the port of Singapore. The goal of the initiative was to provide an integrated system for shipping lines, hauliers, freight forwarders, shippers, and local government agencies that were operating in Singapore (26).

To aid additional global shipping ports, the PSA moved the entire PORTNET system onto the Internet in 1999. Additional ports, such as the Dalian Container Terminals, have employed the PORTNET systems for container management and security. In January of 2001, PORTNET was implemented at the Port of Seattle. The system was used in hopes of improving the flow of information, reducing costs of operation, fulfilling track-and-trace services. The port of Seattle is the only U.S. port to date to utilize the PORTNET system (26).

PORTNET System

The PORTNET system is the world's first nationwide business-to-business port and shipping electronic community. The variety of capabilities includes online documentation systems, tracking services, and real-time information services. In addition to the efficient operation functions, the system also has the following security functions (26):

- Facilitation fulfillment;
- Tracking services;
- Seamless documentation flow; and
- Data and coordination management tools.

These four security functions have been used through the sharing of information and the ability of real-time, on-line tracking. A listing of each function and a description of the services provided is presented in Table 6.

Table 6. Security Functions of PORTNET (26)

Security Function	Description
Facilitation Fulfillment	• Submission of Electronic Bay Plan for locating containers • Submission of vessel itinerary
Track and Trace	• Container handling status • Cargo status (locations, temperature, integrity) • Container location (within port) • Order Status (approved and transshipment connections) • Automated verification, discrepancy checks, and alerts • Event tracking capabilities
Seamless Documentation	• Electronic delivery • Container store and release documents • Government permit applications
Data Management and Coordination	• Schedule details • Ship planning data • Condition updates of “High Risk” containers

BENEFITS OF ITS TECHNOLOGY IN PORT SECURITY DEVICES

The most important benefit that has been identified for the implementation of ITS technology with port security devices has been the tracking of containers and the subsequent ability to gain real-time information on containers and more specifically, high-risk containers. Secondary benefits have also been identified as a result of ITS technology; first, quick and accurate transmission of cargo data and manifest data; second, determination of the containers to be physically inspected at ports; and third, stimulation of port business opportunities.

The primary benefit is to be able to recognize and accurately track high-risk containers. One of the core elements of the Container Security Initiative (CSI) has been to establish criteria to identify high-risk containers. The ability to identify and track such containers would not only aid maritime security of trade and containers, but also ensure the continued smooth flow of containers through seaports. The identification of high-risk containers would improve the operations at seaports, but limiting the number containers that need to be physically inspected (27).

Another important benefit to the increase in maritime security of containers is the increase in economic competitiveness. Ports that utilize increased security and pre-screening become more attractive locations to companies that depend on coordinated movement and just-in-time deliveries. In the event of a security breach involving the use of intermodal containers resulting in a shut down of port operations, these ports that have participated in CSI and implemented the developing security technologies will be able to resume operations quickly and be able to confidently serve the trade community. The perceived benefits of the security technologies are presented in Table 7 (1, 27).

Table 7. Benefits of ITS Technology in Container Security

Security Device	Perceived Benefit
Electronic Seals	• GPS Tracking Capabilities • Real-Time Information on Status and Container Integrity • Monitoring Ability from Origin Port to Destination Port • Ability to Expedite Check-in and Container Clearance Processes
Electronic Manifests	• Secure Dissemination of Cargo Information • Quick, Accurate, and Cheap Transmission of Manifest Data • Advance Notice to Downstream Entities of Container Details
Bar Code Reading Systems	• Container Tracking within Port Facility • Identification of High Risk Containers • Internationally Accepted Practice
X-Ray Inspection Systems	• Monitoring of Containers • Remote Access to Off-Site Monitoring Systems • Ability to Deploy Response Teams • Ability to Warn Transportation Agencies
Gamma Ray Inspections Systems	• Three-Dimensional Inspection of Container • Automatic Inspection Based on Material Specific Signature • Automatic Alert System for Operators • Ability to Deploy Response Teams from Remote Access Monitoring Stations • Ability to Warn Transportation Agencies

CASE STUDY

The literature review and the survey of state Port Authorities yielded a number of security devices that are currently being used and/or being developed. These techniques are to be applied to a theoretical case study to demonstrate the need and applicability of such container security technologies. The goal of the security initiatives has been to apply a multi-layered security program that can be applied to each intermodal container from its origin to its final destination. The existing conditions for the theoretical case study container along with the discussion and recommendation for the implementation of container security devices are outlined in the following section.

Theoretical Container Freight

The theoretical container (Container No. 4273420) contains auto parts that are being shipped from a Chinese manufacturer to a large auto parts supplier in California. The container will be shipped by the manufacturer in China through the Port of Hong Kong to the Port of Long Beach in California. The container will then be transported by truck to the auto parts supplier. In conjunction with the multi-layered security strategy of the Container Security Initiative, any container being exported and/or imported from CSI-cooperating ports must adhere to the guidelines as set forth by the initiative.

The Port of Hong Kong and the Port of Long Beach are two CSI-cooperative port facilities. The entities at each port must communicate the status and manifest of the containerized shipment. In addition to the shipping entities, government groups at each port must also receive notices as to the contents, status, and integrity of the shipment. The Department of Homeland Security (DHS) and the Department of Transportation (DOT) must be kept up to date with the status of the container at its origin so that the manifest can be analyzed by the Bureau of Customs and Border Protection (CBP). Also, the Coast Guard must be able to have access to real-time information in the case of a high-risk container.

Several different security devices are applicable to the fictional container in this situation to provide adequate real-time data from the time the container begins its voyage until it reaches the final destination port. Security devices are also utilized at the port facility so that the container can be monitored before it is deemed safe to be transported to its final destination. The three main stages for the container before it is release from the final port are the following: the origin port facility (Hong Kong), the voyage on the container ship, and the destination port facility (Long Beach). A summary of each stage is discussed and the potential and applicability of each security device during each stage. A flow chart is presented in Appendix B, which shows the summary of the stages for the case study.

Loading at the Port of Hong Kong

The shipping company that is responsible for the shipment of goods has agreed to the guidelines of the Customs-Trade Partnership Against Terrorism as set forth by the Department of Homeland Security. As a result of this partnership, the shipping company must transmit the complete manifest information one day (24 hours) before the container(s) are loaded. By using an electronic manifest transmittal system the manifest data are relayed to the Bureau of Customs and Border Patrol (CBP). The CBP is able to analyze the manifest information by checking it against a series of algorithms in an Automated Targeting System (ATS) to identify any high-risk contents. The CBP officers stationed in the Port of Hong Kong, who are present due to the Container Security Initiative agreement between the United States and China, review the analysis and consult with the host country counterparts. The local review is completed and a message is sent to the shipping company that it is “OK to load” the container.

While loading the container, an option is available to the shipping company on how the container will be sealed. The shipping company has the options to use low-tech, metal seals or bolts to secure the container. The shipping company also has the option to use electronic seals. While both seals are applicable, the electronic seals are recommended based on the tracking and monitoring capabilities. The

electronic seals will be able to notify the Coast Guard and CBP of any breaches when the container is either in a port facility or during the voyage.

Voyage to the United States

Once the container is loaded and cleared in Hong Kong, the vessel can set course for the Port of Long Beach. At this time the CBP transmits the manifest information to the Coast Guard. Prior to arriving in the Port of Long Beach, the vessel operators must send an electronic message to the Coast Guard, identifying the ship and all crewmembers on board. The Coast Guard uses the electronic cargo manifest in conjunction with the real-time data provided by the electronic seal and crew information to determine whether or not the vessel and/or container shipment should be considered high-risk. If deemed a high-risk situation, a large cutter could be deployed to intercept the ship hundreds of miles offshore.

The vessel and container shipment is tracked by the electronic cargo seal and the integrity of the container is monitored. The electronic seal also provides the present position of the vessel while on its voyage to the California coast. Prior to reaching the California coast, the vessel is acquired by radar by the Coast Guard and Marine Industry-operated Vessel Traffic Service (VTS). These tracking devices help in giving location information of the vessel. If security issues were to arise, the Coast Guard and VTS would be able to deploy an armed boarding party, which would consist of Sea Marshals and CBP officials, to board the vessel and conduct searches of the crew and container shipment. Once the vessel and cargo has been cleared, it is allowed to proceed to its berth for unloading.

Docked at the Port of Long Beach

Upon docking at the Port of Long Beach, the vessel is met by the CBP's Contraband Enforcement Team (CET). The CET has received a copy of the electronic manifest via the communications set up and is able to check and verify the containers that are scheduled to be present. Inspectors can also observe if the electronic seal has been tampered with or damaged. Further screening can be performed via video surveillance equipment while unloading the container shipment. The tracking systems will remain intact while the container is stored while it awaits transportation to the auto parts supplier.

The trucking company that is to transport the container to the auto parts supplier must be registered with the port facility. An automatic biometric system will identify truckers as they enter the facility and provide a clearance system as transporters enter and exit the port facility. After being offloaded, the container will either be screened by an X-ray inspection system or a gamma ray inspection system. A non-intrusive, full-truck gamma ray inspection system is recommended so that the three-dimensional screening and material specific signature screening capabilities can be utilized to accurately monitor and observe the container contents while it is cleared for transportation off the port facility and to the auto parts supplier's facility. A bar code reading system can be utilized to identify the container as it exits the port facility to notify the transportation entities that the container has been cleared of the port and passed the multi-layered security system.

The situation described above details the voyage of a fictional intermodal container. The multi-layered security system employs a number of devices and technologies (electronic seals, electronic manifests, bar code reading systems, X-ray inspection systems, and gamma ray inspection systems). The implementation of ITS technology with such devices allows for a free flowing system of information among various transportation and government agencies, real-time tracking of containers, and the capability of quickly and accurately detecting high-risk containers from the time it is loaded until the time it reaches the final destination. ITS technology aids port facilities in effectively operating the movement of containers and provided a means for a multi-layered security system via communication and monitoring capabilities.

A summary of the theoretical case study is presented in Table 8. The term “Applicable” denotes a device that is either currently being used or still acceptable under current security guidelines. The term “Recommended” refers to a device that would meet future CSI Guidelines and provide increased levels of security.

Table 8. Theoretical Case Study Application

Security Technique	Application	Stage of Implementation
Metal Container Seals	✓	Origin Port
Electronic Container Seals	✗	Origin Port
Bar Code Reading System	✗	Destination Port
Electronic Manifests	✗	Origin Port
X-Ray Inspection Systems	✓	Destination Port
Gamma Ray Inspections Systems	✗	Destination Port
Key	Applicable = ✓	Recommended = ✗
Note: Stage of Implementation refers to point at which device is initially utilized.		

DISCUSSION

The need for container security devices has been realized and brought to the forefront due to the impacts of the terrorist threats. In attempt to address this need, the Department of Homeland Security has established two initiatives, the Container Security Initiative and the Customs-Trade Partnership Against Terrorism, to develop security protocols and technologies for national and international port facilities. Some of the current devices being developed are electronic container seals, electronic manifest systems, bar code reading systems, X-ray inspection systems, and gamma ray inspection systems. In addition to such hard devices, software and Internet technologies are being tested to bring together the capabilities of each system to form a multi-layered security system.

The goal of container security devices is to improve security of containers at our nation’s ports and partnering international ports while preserving the operation efficiencies that make the facilities effective means of transportation. These devices work to establish a system to identify and give notice of high-risk containers. The new devices employ ITS technology to improve track-and-trace capabilities and improve communication between the trade industry and governmental inspection entities. As these systems develop they have the ability to provide ports and agencies at ports with real-time information on

location, status, and integrity so that proper protocols can be implemented in the event of a security breach with little or no effect on port facility operations. The potential for electronic communication systems allow for accurate and easy dissemination of data on container cargo and the crew of the ship so that security decisions can be made prior to the vessel's arrival at the port facility. New technology such as gamma ray inspection systems can produce more sufficient monitoring of containers with little disruption in container flow within the port facility.

The cost of implementation of these devices must be addressed early on in order to determine the feasibility of the systems, while the aforementioned security initiatives labor to produce a standardization of the protocols and uses of such devices. The infrastructure involved with these devices must be ensured to be compatible throughout not only national ports, but also international ports as well due to the high influx of goods being imported into the United States from foreign markets.

The current security devices being used and presented the advanced ITS technology that is currently supporting these security devices has been summarized in this report. The security devices being developed is constantly changing and finding new avenues for use of ITS technology, which provide new opportunities for additional research.

In addition to outlining current and developing security devices, a survey of Port Authority officials was conducted to determine benefits and impacts of the intermodal container security devices. The results of the research indicate that not only will the security devices aid in port operations, but will also provide an effective marketing tool for ports. Quick and effective security checks of intermodal containers may stimulate port business opportunities and allow for preferential treatment of participating containers at port facilities.

The future of intermodal container security at port facilities rests in making sure that a comparable and compatible system exists among all interacting ports. In order to experience an overlapping mesh in which a multi-layered security system exists, public agencies and private shipping companies should continue to work together to develop technologies that provide high levels of security while maintaining efficient levels of operations. Researchers should continue their efforts to make the maritime trade industry more secure and safe so that port facilities and the surrounding areas in which they reach can be safer for everyone to enjoy.

ACKNOWLEDGEMENTS

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- Information Services, Massachusetts Port Authority
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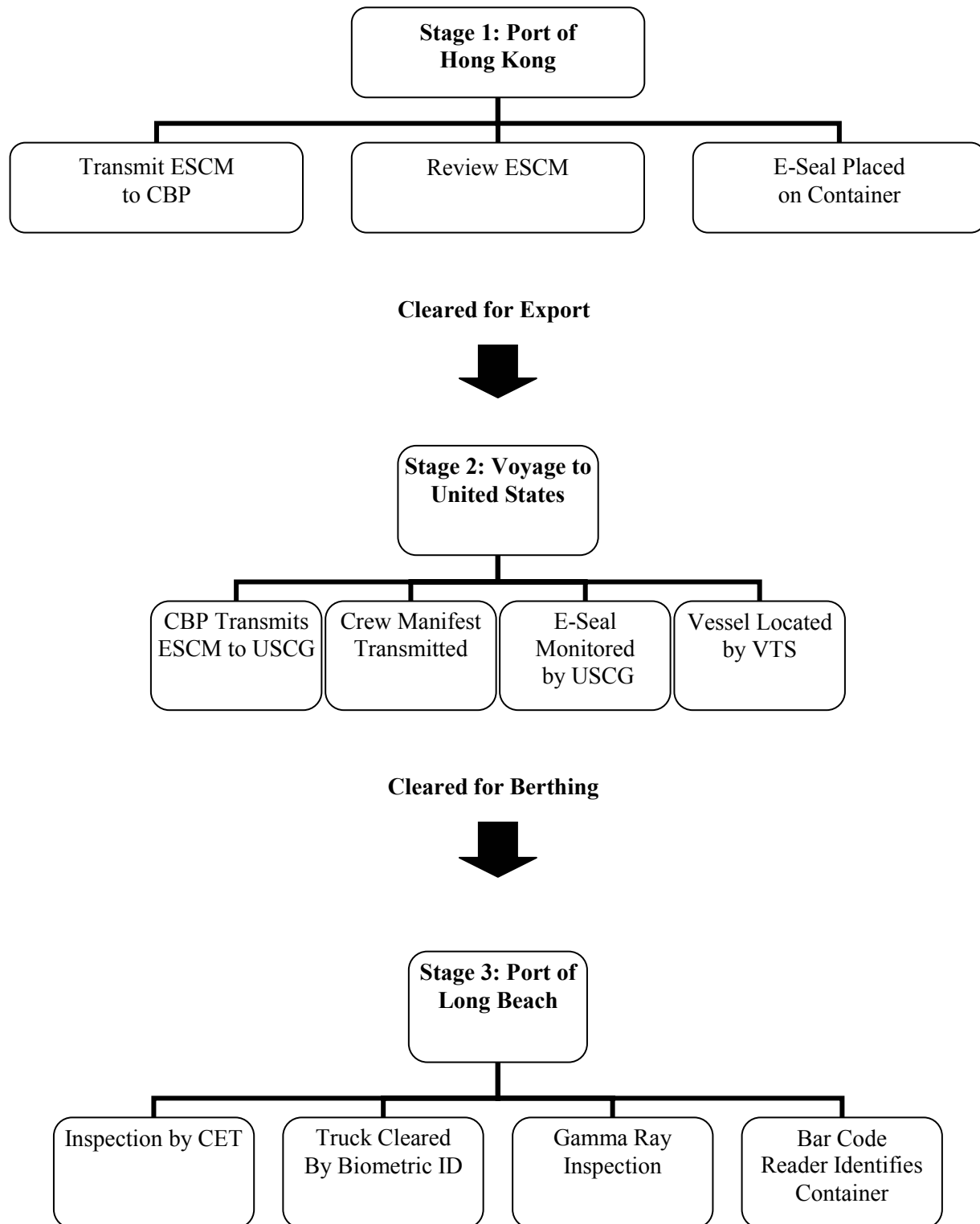
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APPENDIX A: PORT AUTHORITY SURVEY

STATE PORT AUTHORITY CONTAINER SECURITY DEVICES SURVEY	
Name:	
Agency:	
Address:	
City:	
State:	
Phone:	
E-mail:	
Everyday, thousands of containerized freight shipments are imported into the United States. These containerized freight shipments contribute immensely to the health of the economy; however, they do present a security issue. Security devices are being developed and utilized in conjunction with intelligent transportation systems (ITS) technology to allow for better security at U.S. ports and to improve operation efficiency. The purpose of this survey is to gather information on the state of the practice throughout the United States for container security devices. This information will be incorporated into a research paper being prepared for the summer graduate course <i>Advanced Surface Transportation Systems</i> at Texas A&M University. This paper will be used to provide information on current implementation of such security devices as well as identifying the benefits of ITS technology with these devices. Please respond to the following questions as they relate to your port and return your survey results to Tyrell Thompson via e-mail: t-thompson@ttimail.tamu.edu or by fax at (979) 845-6006 by Friday July 11, 2003. If you have questions about the survey please contact me via the e-mail address above or by telephone at (979) 862-8492. The survey can also be conducted by telephone. If you would prefer this method, please let me know and we can set up a time to discuss the survey. I appreciate any information that you are willing to share with me and look forward to hearing your response.	
What containerized freight security devices are currently used within the port facility?	
How is intelligent transportation system (ITS) technology currently utilized with those security devices?	
How was efficiency of operations enhanced and/or is expected to be enhanced after the implementation of ITS technology with the security devices?	
How has implementation of ITS increased the economic competitiveness of the intermodal facility?	
What future security devices and/or ITS technologies are being considered in the future for the intermodal facility?	

APPENDIX B: CASE STUDY FLOWCHART

TYRELL D. THOMPSON

Tyrell D. Thompson received his Bachelor of Science degree in Civil Engineering at Ohio University in November 2002. As an undergraduate, Ty's focus areas were transportation and surveying. Ty's activities included Theta Tau National Engineering Fraternity, Tau Beta Pi Ohio Delta Chapter, American Society of Civil Engineers, and Golden Key National Honor Society. Ty also participated in two design contests, The Big Beam Design Contest and the WERC Design Contest.



As an undergraduate, Ty completed six internships with the Licking County Engineer's Office in Newark, Ohio and two quarters of cooperative education experience with BBC&M Engineering in Dublin, Ohio. While at the Licking County Engineer's Office, Ty performed duties involving surveying, engineering design, traffic studies, and project cost estimation. Many of the projects he worked on were related to the redesign and reconditioning of several county and township roadways. With BBC&M Engineering, he worked on many projects involving highway and heavy construction. Many of his duties involved surveying, construction inspection, material testing, and subsurface investigations.

Ty's current status is that of an Engineer-in-Training. He is currently pursuing a Master of Science degree in Civil Engineering at Texas A&M University. He is currently employed as a Graduate Assistant Researcher at the Texas Transportation Institute (TTI) in the Signs and Markings Program where he is currently working on "Evaluation of Rumble Strips", a project sponsored by the Texas Department of Transportation (TxDOT). He is also a member of the student chapter of Institute of Transportation Engineers at Texas A&M.

Ty's areas of interest include geometric highway design, transportation planning, corridor planning, highway operations, and transportation economics.

A CHECK LIST FOR WORK ZONE INCIDENT MANAGEMENT PLANS

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SUMMARY

To date, a considerable amount of research has been conducted in regards to general incident management on freeways. Likewise, a considerable amount of research has been conducted on work zone management and the effects a work zone has on a freeway system. The research is on the instance that an incident occurs within a work zone and the situations that arise as a result, as well as the effects it may have on the surrounding system.

The overall goal of this research was to devise a check list that will aid in the process of designing a work zone incident management plan that is complete, efficient, and tailored to a specific work zone. The check list will be useful to anyone who may be involved with traffic management through a work zone such as various transportation agencies, project managers, contractors, etc.

A literature review was conducted to acquire a better understanding of past and current practices of incident management. Many general freeway incident management principles can be directly applied to incident management within work zones but other incident management principles must be derived due to additional constraints and limitations posed by the existence of a work zone. A better understanding of issues that commonly arise in other applications of incident management results from the literature review that was conducted. The issues were then properly addressed when developing the work zone incident management plan check list.

A survey of various agencies that are associated with activities conducted in work zones was conducted in order to document some of the current practices relating to work zone incident management. The survey was designed to determine the steps transportation agencies take in order to plan, organize, and design their work zone incident management plans. Overall, the survey was sent to 17 agencies, 10 surveys were sent to public agencies and 7 surveys were sent to private agencies. Seven surveys were returned and synthesized, as documented in the survey section of the report, in order to create a work zone incident management plan check list.

The check list devised is a result of extensive literature research as well as feedback received from professionals in the field. It outlines a basic structure of steps that can be followed in creating a work zone incident management plan. The check list is divided into three different steps: Pre-Plan Necessities, Drafting the Plan, Assessment of Quality and Effectiveness of Plan.

The “Pre-Plan Necessities” portion of the check list is designed to outline the steps that need to be taken in order to begin the entire process. A management structure is described and the process in order to organize the structure is outlined.

The steps that need to be taken and the issues that must be addressed throughout the design phase of the work zone incident management plan are outlined in the “Identifying systems, delegating responsibility, and setting protocols” portion of the check list. Outlined in this step are the various processes that need to be planned and documented for the actual application of the work zone incident management plan.

The next step outlined in the check list is labeled “Specializing the Plan.” The focus of this step is predominantly on customizing the incident management plan in order that special needs of a specific work zone are met. The documentation portion of the plan occurs in this step.

The final step outlined is labeled “Assessing Quality and Effectiveness of the Plan.” This step includes various Measures of Effectiveness (MOE’s) that can be used to assess how well a work zone incident management plan worked for a particular incident. From this assessment the overall plan can be rated in regards to its average performance. Also outlined in this step are the necessary tasks that must be completed following the occurrence of every major incident to ensure the work zone incident management plan is consistently being monitored for performance.

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INTRODUCTION

Problem Statement

To date, a considerable amount of research has been conducted in regards to general incident management on freeways. Likewise, a considerable amount of research has been conducted on work zone management and the effects a work zone has on a freeway system. The research is based on the instance that an incident occurs within a work zone and the situations that arise as a result, as well as the effects this may have on the surrounding system.

There are many things that must be considered when an incident occurs within a work zone. Some of the considerations are similar to those that must be considered in any incident management situation and others are only posed due to the existence of a work zone. For instance, a common work zone is that resulting from the repaving of a highway. For this hypothetical scenario a four lane section of divided highway in a ten (10) mile long work zone is assumed. Generally, conditions permitting, one side of the highway (2-lanes) will be closed and traffic diverted to the opposite side while a section of highway is repaved. This results in a two-lane, barrier divided section of highway. Due to space limitations there are usually little or no shoulders at all. If an incident were to occur in this work zone many issues become present that may not if the incident were to occur in a section of highway that was not within a work zone.

There are many aspects of a work zone that necessitate a more specialized incident management plan, as opposed to simply applying any “general” freeway incident management plan when an incident occurs within the work zone. Though many aspects of a general freeway incident management plan may be applied, there are situations that are created by the presence of a work zone that are not commonly created elsewhere. In the following discussion, three of the many different aspects that may require more attention when developing a work zone incident management plan are addressed. In particular, each of the following: determining the precise location of an incident, gaining emergency vehicle access to the incident, and educating personnel about an incident management plan are briefly discussed.

Incident Location

One potential issue is simply locating precisely where the incident has occurred. When a work zone is implemented, often times existing signing is removed or blocked, including mile marker signing. This creates a problem in responding to the incident, namely emergency vehicle access. When deployed, it is generally assumed the emergency vehicle driver will take the quickest route possible to the incident. Without proper knowledge as to the exact location where the incident has occurred, the response time may be greatly affected. If there is a major cross street intersecting the highway within the work zone it may be quicker for the emergency vehicles to gain access to the incident by way of ramps from a cross street in order to arrive at the incident in the shortest amount of time possible. On the other hand, if the location of the incident is not known, emergency vehicles may be required to travel the length of the work zone thus adversely affecting potentially critical response time that could have been minimized.

Emergency Vehicle Access

Another potential issue is emergency vehicle access. Specific plans pertaining to how drivers of emergency vehicles will most efficiently gain access to an incident that has occurred in a work zone need to be pre-specified and understood by each responding agency. For example, if an incident occurs blocking the single lane of travel, and no shoulders are present throughout the work zone, it may not be possible to gain access to the incident by the direction of travel in which the incident has occurred. In this case it may be more effective to gain access to the incident from the opposite end of the work zone. This situation could become very complex and dangerous if not properly planned. Pre-planning for these types of situations will prove beneficial should this instance present itself.

Incident Management Plan Education

A third potential issue in incident management within work zones that must be considered is contractor/work crew education. The contractor must know the proper plan of action that must be taken in the instance an incident was to occur. Furthermore, the contractor must make arrangements to educate the work crews in the same manner. In the initial planning phases of a work zone, it may be beneficial to devise a plan of action pertaining to each separate phase of a construction project. This plan may take specify courses of action such as, among others, where to move the equipment, who must be contacted, the sections along the work zone that may need special attention, and what route diversion plans need to be executed contingent upon the location of the incident.

Devising a properly structured incident management plan within a work zone that covers these three issues, and others, is not only necessary from the standpoint of minimizing the effects of an incident but may be necessary in saving a motorist's life. The results of this research will produce a check list by which an agency can devise an incident management plan assuring the most crucial aspects are addressed and planned. The check list will be created based on past experiences and will utilize innovative strategies in the detection, verification, response, and clearance of an incident within a work zone.

Research Objectives

The overall goal of this research was to devise a check list that will aid in the process of designing a work zone incident management plan that is complete, efficient, and tailored to a specific work zone. The check list will be useful to anyone who may be involved with traffic management through a work zone such as various transportation agencies, project managers, contractors, etc. The specific objectives of the research were:

- Review general and work zone incident management principles and procedures based on past literature;
- Determine what procedures highway agencies are currently utilizing for incident management within work zones;
- Identify the practices that resulted in efficient mitigation of an incident within a work zone
- Create a check list for state DOT's based on the most efficient incident management practices list, helping to create a structure for managing an effective incident management plan within a work zone; and
- Provide the check list to an agency managing an existing work zone for use in a future incident management situation and document the feedback.

Scope

A check list was created for use in developing an effective and complete work zone incident management plan based on past experiences. The scope of the research only included freeway work zones. Non-freeway work zones were not considered. The literature search was not limited to research of work zone incident management in the United States. International research was not excluded and was considered as a viable source for work zone incident management research. Only agencies within the United States were contacted for current practices. The final check list developed from the research was applied to a location within the United States. Though the check list is anticipated to be applicable to most work zone situations internationally, it was beyond the scope of this project to research applications internationally.

STUDY DESIGN

The procedures followed in carrying out the research in order to develop a work zone incident management plan check list were categorized into five main tasks. These tasks are discussed throughout this section.

Literature Review

A literature review was conducted to acquire a better understanding of past and current practices of incident management. Many general freeway incident management principles can be directly applied to incident management within work zones but other incident management principles must be derived due to additional constraints and limitations posed by the existence of a work zone. As a result of the literature review, a better understanding of issues that commonly arise in other applications of incident management such that those issues were properly addressed in the development of a work zone incident management plan.

Develop Contact List for Surveys

Many different agencies are currently utilizing general incident management plans but the goal of this research was to locate agencies that are known to utilize some type of incident management plans, particularly for application in work zones. A contact list was developed based on telephone calls and e-mails to transportation professionals inquiring their knowledge of agencies that may be good resources for this information.

Conduct Surveys

Once the contact list was developed, a survey, found in Appendix A, was created and sent to the various agencies. The surveys were designed to determine the steps these specific agencies take in order to plan, organize, and design their work zone incident management plans. The survey was sent to 17 agencies, 10 surveys were sent to public agencies and 7 surveys were sent to private agencies. Seven surveys were returned and synthesized, as documented in the survey section of the report, in order to create a work zone incident management plan check list. All seven transportation agencies that returned surveys were public agencies.

Create Work Zone Incident Management Plan Check List

The information gathered from both the literature review and the returned surveys was used to create a check list that outlines steps to be taken in the planning, organizing, and designing of a work zone incident management plan. The check list is an attempt to create a general structure that can be followed in order to aid in the design of a complete and effective work zone incident management plan.

Check List Application

Once the check list was created it was sent to three professionals in the field for review. Critiques were sent back and the check list was revised. The revised check list was then sent to a project manager of a major project on a Florida interstate. The project manager then applied the check list to an incident that recently occurred and depicted the areas of the check list that were followed and the areas that were not followed. The project manager then gave feedback in relation to the checklist describing if the portions of the check list that were not used could have been useful. The incident is described and the project manager's comments are summarized and documented in the final section of the report.

LITERATURE REVIEW

A literature search was conducted pertaining to general incident management as well as incident management within work zones. Initially, the Federal Highway Administration (FHWA) and the United States Department of Transportation (USDOT) websites were searched for related literature. More resources were then acquired from the National Transportation Library which was searched via the search engine also known as TRIS Online.

Throughout this section of the report, the literature is summarized and categorized into four different sections. The first section is a summary of some of the literature found in relation to general freeway incident management. This section is a brief overview of the general principles of incident management on freeways. The second section is a summary of the many lessons learned based on general incident management plans from various sources. Depicted in the next section are issues and aspects of a work zone and how work zones may adversely affect different aspects of a general incident management plan. The fourth and final section is a summary of the limited amount of literature found that specifically discussed work zone incident management plans.

General Freeway Incident Management

Incident management, as indicated by the FHWA, “refers to a coordinated and planned approach for restoring traffic to its normal operations as quickly as possible after an incident has occurred.”⁽¹⁾ Once an incident occurs, congestion is normally a resulting consequence. Incidents are assumed to cause congestion due to the temporary loss of capacity, while the demand remains constant or even possibly increases. Congestion can be defined by two different classifications: recurring congestion and nonrecurring congestion.

Recurring congestion exists when the demand of a particular section of roadway exceeds the physical capacity of that section of roadway. The most common recurring congestion results from what is often defined as “rush hour” which generally exists during the a.m., noon, and p.m. peak periods. This congestion is mostly predictable in regards to location, time, and duration.

Nonrecurring congestion is caused by a temporary reduction in capacity or a temporary increase in demand. Nonrecurring congestion is either not predictable (a stalled vehicle in the roadway) or completely planned (traffic generated by a special event). “Most of the activities that cause recurring congestion can be classified as incidents”⁽¹⁾

Due to the unpredictability, nonrecurring congestion is considered a high safety hazard, especially on high speed facilities such as freeways, and special attention needs to be devoted to limiting the number of motorists exposed to this potential hazard. The ultimate goal in an incident management plan is to limit the amount of time the incident remains, causing a reduction in capacity.

As displayed in Figure 1, there are three identified processes that consume crucial time and that can be minimized through proper coordination once an incident occurs: 1) Detection, 2) Response, and 3) Clearance. In addition, recovery of roadway capacity is a factor in the overall time it takes for traffic to return to normal flow but is only a result of traffic flow conditions as governed by the physical roadway. Figure 1 does not depict the recovery of roadway capacity as something that can be “controlled” by an incident management plan but there are in fact processes that minimize this time. The minimization of any or each of these identified processes will result in an overall decrease in the time to normal flow, thus minimizing exposure of other motorists and required personnel to secondary incidents.

“Incident detection and verification is the process of determining that an incident has occurred and communicating this information to the appropriate agencies.”⁽²⁾ Incident response is the process of communicating the correct and needed information to the necessary agencies and the ability of the

respective agencies to gain access to the incident with the equipment needed. Incident clearance is the process of the multiple agencies working together once arriving at the incident in order to clear the roadway of the incident. Recapturing of roadway capacity is the time it takes traffic to resume normal flow following the clearance of an incident.

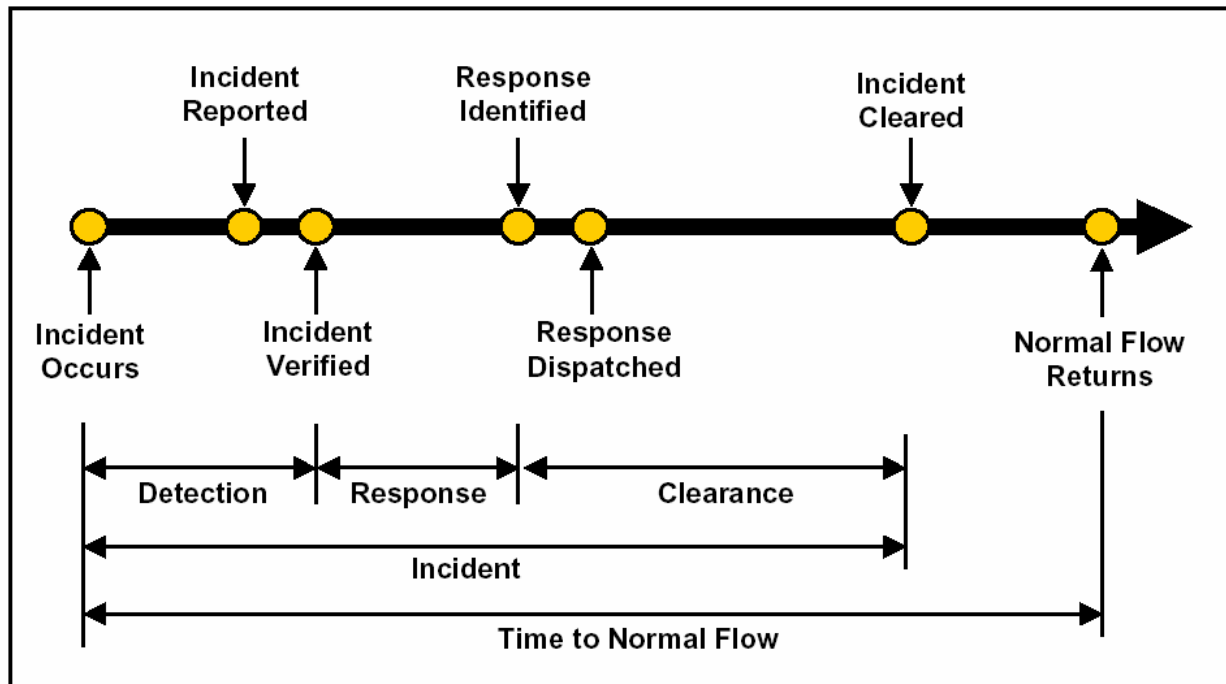


Figure 1. Tasks Required to Detect, Respond to, and Clear Incidents (2)

An incident management plan is a pre planned procedure that identifies the proper steps to be taken, and the proper order of application, in the detection, verification, response, and clearance of an incident, prior to the incident occurring. Many different resources are used in order to most efficiently accomplish this process. “Resources are used to increase the operating efficiency, safety and mobility of the highway by systematically reducing the time to detect and verify an incident occurrence; implementing the appropriate response; and safely clearing the incident, while managing the affected flow until full capacity is restored.”(3) In conclusion, an incident management plan is established to utilize all available resources in order to successfully accomplish efficient incident management.

When organizing an incident management plan, many different things need to be taken into account. All the processes highlighted in Figure 1 are very important aspects of an incident management plan, but an incident management plan is not set up in order to solely address those issues. However, if an incident management plan is properly planned, designed and operated then the time involved with each of the processes listed in Figure 1 will be minimized, simply in the use of an efficient and conclusive incident management plan.

There are many complex and often times complicated steps that are encountered in the planning, design, and operation of an incident management plan. The initial step in the planning process of an incident management plan is to determine what is needed for the specific location the plan is being drafted. In other words, goals need to be set, and measures that need to be taken in order to accomplish those goals need to be identified.

Lessons Learned

Past experiences have proven to be very useful in defining processes that work and do not work in both the planning phase of an incident management plan as well as in the application of an incident management plan. Some of the more important issues addressed by the Virginia Department of Transportation are: the early design of a plan, communication, data collection, marketing of a plan, measures of effectiveness for a plan, flexibility of a plan, and interagency communication and coordination.(4)

Devise a Plan Early

An incident management plan should be coordinated with the planning and design phases of a project rather than just prior to construction of the project. In the early development of an incident management plan, impacts resulting from different strategies can be better evaluated and more easily tailored to the specific needs of the project.

Interagency Communication/Coordination

Communication is very important in the successful deployment of an incident management plan. “Effective traffic incident management requires a comprehensive, integrated planning process that involves all potentially affected stakeholders, including traffic engineers, highway maintenance personnel, law enforcement officers, fire and emergency medical responders, towing and recovery operators and a range of other professionals – from federal, state and local agencies as well as private sector, volunteer and contract agencies – who play a role in incidents and emergencies on the roadway.”(5) Communication among all of the potentially effected agencies must be established early on in the planning stages and maintained in order to assure each of their needs are met.

Data Collection

It is recommended that a base year database be established in order that the effectiveness of the incident management plan can be monitored throughout project. There will be base year data that are already available and an assessment of the data that is not available needs to be taken in order to establish the collection of the needed data. In some instances, some data may need to be collected prior to the onset of construction thus the assessment of the needed data must be conducted early such that the beginning construction is not delayed.

Marketing

Marketing of the incident management plan is critical and has proven to be highly effective. Marketing refers to not only the motoring public but to ensuing transportation agencies and contacts as well. If the plan is properly marketed less resistance will be encountered throughout the implementation and benefits

Measures of Effectiveness

Measures of effectiveness need to be established such that performance of the incident management plan can be routinely monitored. If the measures of effectiveness that are established early in the planning phase of the incident management plan regularly display insufficient performance by the plan then changes to the plan need to be made to ensure the plan is meeting the goals and objectives that are expected to be met.

Flexibility

The incident management plan needs to be designed such that all aspects of the plan display flexibility in its design. It is important that the plan remains flexible otherwise changes that potentially need to be made to ensure the plan is performing up to set standards may not easily be incorporated. Depending on the length of the plan it can almost be assured with the constantly changing conditions in the field, priorities, and problems the plan will necessitate constant change. In this manner it must be made as simple as possible to change certain aspects of the incident management plan to keep the plan as tailored to the situation as possible.

Work Zones as a Special Case

Incidents are defined as any non-recurring event that causes a temporary reduction of roadway capacity or an abnormal increase in demand.(3) In this definition work zones themselves are defined as incidents since they often times cause a temporary reduction of roadway capacity. Congestion is caused as a result of the temporary degradation of the capacity of a roadway. Congestion caused by work zones is a source for many problems. In fact, nearly 55 percent of congestion is caused by incidents in urban areas, and 100 percent in rural areas.(7) Anytime congestion occurs, the potential for serious secondary incidents increases greatly and the severity of secondary crashes is often greater than that of the original incident.(3) In California it was shown that secondary crashes represent an increase in collision risk of over 600 percent.(8) The length of time other motorists are exposed to congestion that is created by an incident needs to be minimized in order to limit the high risk of serious secondary incidents.

The topic of a work zone incident management plan is in essence, by all means of the definition, an incident management plan created to manage an incident within another incident. An incident that occurs within a work zone can actually be defined as a secondary incident and range from a vehicle stranded with a flat tire to an overturned commercial vehicle. Both situations have the potential to block lanes of flow and require equal seriousness in the detection, verification, and response time. In addition, the situations are made more complicated as a result of the restrictions placed on the site. Work zones can be in place for something as simple as repairing a roadway abnormality or as complex as rebuilding a bridge structure. Regardless of the reason, work zones reduce roadway capacity and create potentially hazardous situations for both motorists and working personnel. More than 800 fatalities and 370,000 injuries a year are a result of work zones.(6) From these high numbers of fatalities and injuries caused as a result of work zones it is inherent that most of these incidents occurred within the work zones themselves. It is obvious that this concept of an incident occurring within another incident is a common occurrence and deserves special attention.

Incident Management in Work Zones

Restrictions created from a work zone that is in place in order to correct a small roadway abnormality, and restrictions created from a work zone that is in place to rebuild a bridge structure may vary greatly in magnitude but both must be considered for proper incident management. Some cases may restrict a normally four lane median-divided freeway into a two lane barrier-divided freeway affecting both directions of travel on a freeway and some cases may simply affect one direction of travel of freeway by closing a single lane of travel. Regardless of the magnitude of the effect the work zone has on the operating conditions of a freeway, the fact that an effect is present makes the necessities of a work zone incident management plan different from those of a general incident management plan.

Prior to the onset of construction, a properly designed incident management plan will take into account each phase of expected construction. Key points of the incident management plan need to address, among other aspects, locating the incident, emergency vehicle access to the incident, and incident management plan education.

In 1998 the Federal Highway Administration (FHWA) began a survey of 26 different states seeking the current best practices in the United States in relation to work zones. From this research, a work zone guide book has been assembled that lists all the best practices and the states that practice each of them. This research is on going and best practices are continually being appended to the document such that an updated list of best practices is always available. In the work zone guide book a section is devoted to incident management best practices within work zones. Table 1 is a summary of the listed best practices of work zone incident management by state.(Z)

Table 1. FHWA Work Zone Incident Management Best Practices (Z)

State	Best Practice/Policy	Description	Biggest Benefit
California	Incident management in work zones	Designated towing service responsible for keeping work zone free of disabled vehicles	Quick response time is crucial and results in an exponential decrease in queue lengths and motorist delays
Illinois	Emergency traffic patrol motorist assistance and Incident management program	Emergency traffic patrol correct breakdowns, push or tow vehicles, and upright and move tractor trailers. Crash investigation sites are established	Helps minimize the negative effects on traffic flow that result from vehicle breakdowns and traffic crashes.
Indiana	Hoosier Helper	Incident response vehicles to assist stranded motorists and remove disabled vehicles. Advise motorists of crash-related congestion by HAR, VMS, and pagers from scene of crash	Restoring Capacity
Iowa	Project monitoring with Incident response	Contract services provide 24-hr continuous monitoring of traffic control devices and incident response. Contractor traverses work zone providing assistance to motorists and TCD's.	Better traffic flow and prompt notification of incidents and problems.
Mississippi	Incident management special provision in construction contracts.	Special provision outlined responsibilities of the contractor so that contractor became part of the incident management team with responsibility of reducing traffic delay and providing access to the site for emergency vehicles	Contractor became a partner and was involved in making decisions with the Incident Management Team rather than an adversary
North Carolina	Incident Management Inter-Agency Teams	Representatives from Emergency Response agencies meet periodically to improve response and clearance of incidents	Emergency response agencies are able to access the scene and care for the injured quickly. Quick response and clearance by predetermined alt. route detours helps maintain traffic flow
Oregon	Incident Management in the Westside Corridor work zones	Incident response program involved detection and verification of an incident, response and removal of obstructions, traffic management, and motorist information	Reduced delay and enhanced safety in work zone and the program fosters good will with the public
Pennsylvania	Incident management meetings on construction project	Incident management plan is required on long-term construction projects. Freeway projects normally require a preconstruction meeting with emergency responders	Effective response and reduced delay
Pennsylvania	Motorist services	Use of tow truck for incident management on long-term freeway work zones	Improved public image and Incident management
Utah	Contractor furnished service patrols	Service patrols consist of vehicles equipped to handle minor vehicle problems such as flat tires, overheating, out of fuel, etc.	Decrease in congestion due to "rubber-necks," assistance to stranded motorists, and good public relations with the community
Utah	Emergency response team and Trucking Association involved in the design/evaluation of the traffic control plan	Cooperative effort of all emergency response agencies, private sector companies, and media to institute a limited access contingency plan and a proactive response to emergency situations	Coordination of the parties involved allowed emergency response agencies and private sector companies to have input into the overall traffic control plan
Utah	Work Zone incident management provisions in construction contracts	Requirement for contractor to provide courtesy patrol services. Courtesy patrol will provide travel info., fuel, tire changing assistance, pushing of vehicles to pull-out locations, arrangements for towing service, and placement of cones and safety flare	Reduction of motorist delay and improved safety through the work zone, as well as improved confidence by the public in transportation services

SPECIAL CONSIDERATIONS OF DESIGNING A WORK ZONE INCIDENT MANAGEMENT PLAN

A work zone incident management plan uses the same principles and concepts that a general incident management plan uses, only in the case of a work zone, it is especially important to specialize an incident management plan to cater to the specific needs of a particular work zone. A work zone alone can be considered an incident due to the fact that they often have adverse effects on normal operations of a freeway. When a separate incident occurs within the work zone, a very complex situation is created and must be addressed, it is in essence an incident within an incident. Without proper planning and organizing the process of managing an incident within a work zone can become disjointed, and critical time can be lost, further exposing emergency personnel, work crews, and motorists to dangerous secondary incidents.

Discussed in the following section are different aspects that are most important in designing a work zone incident management plan. Though many of the topics parallel those that would be utilized in designing a general incident management plan, an attempt is made to discuss how and why these particular topics are most important to the work zone incident management plan designing process.

Establishing Interagency Cooperation/Coordination

Interagency cooperation and coordination is essential in the implementation of a work zone incident management plan. Not only are good working relationships necessary among the different agencies that are important in the planning and designing phase of a work zone incident management plan, they are necessary following the occurrence of an incident. Agencies must cooperate with one another to efficiently respond to an incident, manage activities on-site, and clear the incident.

These interagency relationships need to be established prior to and during the planning phases of a work zone incident management plan. If these relationships are never established or are only established following the occurrence of an incident then the latency of establishing these necessary relationships may result in unnecessary confusion and an inefficient application of a work zone incident management plan, essentially defeating the purpose of having an incident management plan that may have consumed many hours in its design.

Good working relationships need to be established early in the planning phase and maintained among the following types of affected agencies: (3)

- Law Enforcement
- Fire and Rescue
- Emergency Medical Services
- Transportation Agencies
- Towing and Recovery Service Providers
- Media
- Information Service Providers
- Coroners and Medical Examiners
- Hazardous Materials Removal Services

Each of these agencies maintains different responsibilities once an incident occurs. Relationships need to be established not only to ensure proper coordination among agencies but also to clearly define the roles and responsibilities of each agency. If these are not clearly defined early, agencies may duplicate tasks which results in wasted time and efforts that may be needed elsewhere at the incident site during a critical period of time. This is especially important when responding to an incident that has occurred within an

work zone due to the additional agencies that are present at a work zone that may not regularly be present in a general freeway incident management scenario.

Incident Detection

Incident detection is the initial step in conducting a work zone incident management plan. Once an incident occurs within the work zone it is valuable to determine that an incident has occurred within the shortest amount of time possible. Once the incident is detected agencies can be alerted that there is a potential need for them and proper preparations can be made for carrying out the remainder of the work zone incident management plan. In addition, from a safety standpoint, victims are most generally in their most critical state from the time the incident initially occurs to the time the first responder arrives to the site. Also, the more time that passes without warning motorists of conditions the more exposure exists of a severe secondary crash. In lieu of the dangers that occur at the site once an incident occurs, as well as the need to alert the necessary agencies to be on stand by, incident detection time needs to be kept as short as possible.

There are many different systems that are currently used to minimize incident detection time. Some commonly utilized systems that have proven effective and efficient are as follows:(3)

- Infrared Detection
- Video-Image Processing
- Closed Circuit Television (CCTV)
- Vehicle Probes
- Automatic Vehicle Identification

Each of these processes are highly innovative and can become quite costly to the project but the benefits that they can provide in shaving critical time in the overall incident response time can prove highly beneficial. Careful time needs to be taken in determining the type of detection system that is needed and which detection system would best fit the needs of the particular work zone in question.

Incident Verification

Incident verification is the process of summarizing the information obtained from the incident detection process and verifying that all the information obtained is accurate. At this point, as much information about the possible incident needs to be obtained and verified. The most critical information includes the type of incident, the severity of the incident, the location of the incident, and the direction of travel in which the incident occurred. All this information will be utilized by the dispatchers to deploy the proper equipment and personnel in the response portion of the work zone incident management plan.

Some of the same systems that are utilized in the incident detection phase of a work zone incident management plan can also be used to verify the required information. For example if CCTV is utilized throughout the work zone the incident can both be detected and information about the incident can be verified by the real time connectivity of dispatchers to the work zone. In some instances not all the necessary information may be readily available through the CCTV system. An incident that has occurred may be detected but the view to obtain the necessary information may be obstructed, a necessary camera may have been damaged in the incident, or the incident may have simply occurred just out of detailed view of the cameras. Any number of possibilities may exist, therefore other means of verification need to be in place. The following means of verification are commonly used and need to be considered in the design of a work zone incident management plan:

- Closed Circuit Television (CCTV)
- Field Units (maintenance crews, police, contractor personnel, service patrols)

- **Multiple Motorist Reports**

Opportunities for quick detection and verification of an incident potentially exist more so in work zones than may elsewhere. If the work crews and/or contractors are present and are educated about what information is needed and whom to contact with the information then the incident detection and verification time can be greatly lessened. The opportunity may be wasted if the personnel present in the field are not educated of the steps to take and who to contact once an incident occurs. In addition, a common practice is to have an off duty officer present at work zones throughout the peak hours of the day. If an officer is present when an incident occurs, control of the incident site can be taken immediately and responding agencies can be quickly notified.

Incident Response

Incident response requires taking all the information detected and verified and relaying the proper information to the proper agencies. It is essential from this portion of the work zone incident management plan that lines of communication are established, maintained, and efficient. The information relayed to the agencies must be accurate such that the proper agencies, equipment, and personnel are deployed in a timely manner.

Once the respective agencies are contacted it is their responsibility to deploy the proper equipment and personnel based on the information received. If the incorrect equipment is deployed or not enough personnel deployed, the response time can be unnecessarily long. Relaying inaccurate information can result in this wasted time as well; therefore the information relayed to the agencies must be accurate. In this manner the response time is partially a function of the accuracy of the detection and verification of an incident, but can be minimized if all of the necessary information is gathered and verified accurately.

A crucial portion of the information needed for responding agencies is the location of the incident and the conditions at the site. If a responding agency can not gain access to the incident from the direction of travel in which the incident occurred, other methods for gaining access to the incident must be utilized. Emergency access plans must be defined for each separate phase of construction. These emergency access plans must be planned as part of the work zone incident management plan, otherwise crucial time may be lost attempting to determine how to get emergency equipment and personnel to the incident site.

On-Site Management

On-site management refers to the period of time following the initial responders arriving at the site of the incident. Again interagency cooperation and coordination is important at this point. It is not uncommon to have many different agencies at the site at any given time. Each agency needs to be educated of their responsibilities along with each other responding agency's responsibility. This will help to ensure agencies do not overstep their responsibility boundaries which could result in wasted time and energy and add unnecessary confusion to the situation. These responsibility boundaries should be planned and in place prior to the agencies arriving on site.

On-site management can be divided into three different management groups: incident site management, traffic management, and motorist information management. Each of these management groups are equally important and play vital roles in the overall successful management of personnel and agencies on-site.

Incident site management refers to the management of activities of the personnel actually at the site of the incident. Some incident site management tasks include securing the site to ensure a safe work environment for rescue crews, tending to victims, incident investigation, etc. Each of these listed tasks is generally performed by different agencies and the incident site manager will be the individual who oversees all the coordinated work that is being done at the site of the incident. In addition, the incident

site manager will have the responsibility of relaying all necessary information to other task managers as well as to the dispatch location.

The traffic management group will be responsible for all decisions and aspects pertaining to traffic in the field. The group will be in charge of ultimately making the decision to re-route traffic to a pre-planned alternate route if necessary. The group will also be in charge of setting up necessary equipment such as traffic cones, traffic barrels, flares, etc. that will aid in the diversion and control of traffic at the site.

The motorist information management group will be responsible for relaying all necessary information to the motoring public. Once an incident occurs it is important to get accurate information out to motorists as quickly as possible. The most important task of the traffic management group will be to warn approaching motorists of the conditions and make the decision of diverting traffic to an alternate route based on the conditions at the site of the incident. This type of information is most easily relayed to the motoring public in the vicinity of the incident by utilizing Portable Changeable Message Signs (PTMS) and Dynamic Message Signs (DMS).

Once all necessary decisions are made regarding all the traffic that directly effected by the incident, the traffic management group must focus on getting information out to the motoring public in the surrounding areas so that they can re-route their trip in order to avoid the area all together. Relaying information to the public not in the immediate vicinity of the incident is generally done through media outlets such as radio and/or television, Highway Advisory Radio (HAR), and DMS's that are in place in other areas as part of a traffic management center.

Incident Clearance

Incident clearance includes the removal of debris, wreckage, spillage, etc. from the roadway in order to allow the roadway to return to normal operating conditions. It is critical to clear the roadway in the shortest time possible. This portion of the work zone incident management plan could potentially take the longest period of time.

In order to minimize clearance time it is important to have the proper equipment at the site and ready to begin removal once the victims are removed and the investigation of the incident is complete. Getting the proper equipment to the site should be a result of incident response.

Many different techniques have been and are currently used that have proven to shorten clearance times. One such technique is creating public contracts with towing agencies. Contracts can be made with towing agencies that will ensure the towing company that is contacted will have the proper equipment to do whatever job needs to be done and will be ready to respond with short notice. The process of forming a contractual agreement with a single or several towing agencies can be beneficial but careful time must be taken in planning such a process.

Another technique that helps contribute to a minimal clearance time is the designation of a drop area. A drop area is a pre-specified location where debris, vehicles, victims, etc. can be taken out of the travel lanes. In the drop areas incident investigations can be completed and police reports can be filled out without adding addition unnecessary time that the lanes of travel are inhibited. This is a simple and cheap solution to lessening clearance times.

Recovery

Recovery refers to the period of time required for the roadway to return to normal operating conditions within the work zone once the incident is cleared and traffic allowed back through, as it was prior to the incident occurring. For this portion of the work zone incident management plan it is important to determine the length of time a diversion needs to remain in place before traffic can be safely allowed to

travel through the work zone. In addition, once the decision is made to allow the traffic to travel through the work zone, consideration needs to be given how to most efficiently re-open the traveled way.

SURVEY RESULTS

One of the objectives of the research was to determine the current state of practice with regard to work zone incident management plans. Both public and private transportation agencies were contacted and sent electronic surveys in order to receive feedback from various viewpoints. The agencies were queried of existing practices relating to work zone incident management plans. The survey was electronically sent to 17 different transportation agencies, both private and public. A sample survey can be found in Appendix A, Interview Questionnaire. Responses were received from 7 different agencies, coincidentally the 7 responding agencies were public transportation agencies. The agencies that responded to the survey were as follows:

- California Department of Transportation (Division of Maintenance)
- California Department of Transportation (District 11 Transportation Management Center)
- Maryland Department of Transportation
- Minnesota Department of Transportation
- North Carolina Department of Transportation
- Ohio Department of Transportation
- Texas Department of Transportation

Majority of the agencies fully completed the surveys and returned them although two agencies completed the surveys in portion and returned them. The following discussion is a summary of survey responses in relation to what the responding agency provided. It must be noted that each responding agency felt a checklist that structured the most important steps in the development of a work zone incident management plan would be beneficiary.

Survey Responses

California Department of Transportation (Division of Maintenance)

The maintenance division of the California Department of Transportation conducts maintenance related projects along roadways. These projects are predominantly short term projects and do not disrupt traffic long enough to require the draft of a major work zone incident management plan. There are no written guidelines or steps to be followed when devising any sort of work zone incident management plan. The contractors are educated of procedures and responsibilities through tailgate safety meetings. These safety meetings are generally on-site, informal type meetings. In the meetings, contractors are required to discuss options of “what happens if...”

Practices they have found to be the most effective in managing an incident in a work zone are contacting law enforcement early and urging early intervention by law enforcement. One means of providing early intervention by law enforcement is to have off duty officers sitting in patrol cars on site during the most critical hours of the day.

The Division of Maintenance has heavily relied on cell phones as the predominant means of communication but scanners are used as well.

Table 2. Survey Response Summary

	California DOT (Division of Maintenance)	California DOT (District 11 Transportation Management Center)	Maryland SHA	Minnesota DOT	North Carolina DOT	Ohio DOT	Texas DOT
Is there a current list of steps you use to help guide the planning phase of a WZIMP?	No	No	No	In development	No	Yes	No
Is a plan established for each WZ, and each phase of construction, to manage incidents?	No	Only for projects > \$15,000,000	Contingent on size of project	In development	No	Only for projects where lane closures are expected for 6 mos. or more	No
How are contractors/work crews educated about WZIMP's?	Tailgate safety meetings	Contractors are told what is expected of the work crews in pre-construction meetings	Pre-Construction meetings	Pre-Construction meetings	None	Left up to contractor, project engineer, and inspectors	None
Most effective practices that have been used in managing incidents in WZ's?	Early intervention by law enforcement and utilizing PCMS's	Dispatching traffic management teams and the highway patrol to establish command at which point a determination is made regarding other personnel, equipment, detours, etc.	Well defined roles/responsibilities and efficient lines of communication	Surveillance incorporated into an operations system	Did not answer	Pre-specified alternate routes, priority contact list, debriefing meetings	Coordination with construction personnel
How are efficient lines of communication established and maintained?	Rely heavily on cell phones and scanners	List of personnel contacts and phone numbers for all agencies	Sharing frequencies	Same communications utilized in daily operation of the TMC	Did not answer	Currently telephone but working on establishing an official police and fire two-way radio with communication privileges	Common communications
Would a check list be helpful in the development of a WZIMP?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Innovative ideas that may advance the effectiveness of a WZIMP?	N/A	Utilize the development of current technology to improve the response time	Utilize ITS to improve response times and reduce traffic delays	Work closely with TMC and maintenance crews	Did not answer	Use construction equipment to improvise	WZ configuration should be designed for motorists and not contractors

California Department of Transportation (District 11 Transportation Management Center)

It was expressed that there is a list of steps established by which to follow should an incident occur. If an incident occurs in an active work zone response teams including highway patrol will respond to the site for containment. A coordinated effort that typically includes the contractor will proceed with managing and clearing the incident. These steps are only established and implemented for major construction projects exceeding \$15,000,000.

Educating the contractors and work crews typically occurs during pre-construction meetings. During these meetings the contractors are educated and are informed of what will be expected of their work crews. It is then the responsibility of the contractor to educate the work crews.

The practices found to be the most effective in managing an incident in a work zone were given to be verifying that an incident has occurred and dispatching traffic management teams and the highway patrol to establish command. A determination should then be made regarding other personnel, equipment, detours, etc.

Efficient lines of communication are established and maintained by creating a list of personnel contacts. This list includes phone numbers, both cell phone and pagers, and is available from all agencies that may be needed to help clear an incident.

Maryland State Highway Administration

Maryland reported that there was no known general list of steps that have been established in order to help guide the planning phase of a work zone incident management plan. Although, depending on the size of the project and its potential impact of traffic flow work zone incident management plans are discussed and drafted. For major projects, work zone incident management plan committees are created

to develop the plans. For all other construction projects, incident management is discussed in pre-construction meetings with various State highway agencies, law enforcement agencies, emergency response agencies, and contractors.

When work zone incident management plans are drafted, they generally include project related information to minimize incident response time, roles and responsibilities of various agencies, and communication methods for sharing information and data. Often under the work zone incident management plans the contractor is assigned many responsibilities, some of which may include notifying different agencies about an incident and setting up roadway and lane closures to facilitate incident responses.

Contractors and work crews are trained through the pre-construction meetings as well as other meetings throughout the various phases of the project. In addition there is a Traffic Manager training course for temporary traffic control that is currently being revised. Following the current revision a “things to do” list in the case of an incident will be included in the training session. A trained Traffic Manager is required at every project.

The practices found to be the most effective in managing an incidents in work zones are maintaining well defined roles and responsibilities as well as an efficient line of communication between all agencies involved in the response of an incident. These practices are key to the successful execution of an incident management plan.

In maintaining efficient lines of communication the Maryland Department of Transportation depicted a specific method, sharing radio frequencies, in an attempt to efficiently relay proper information. This method among others is established as part of the State Highway Administration’s statewide Freeway Incident Management Plans. The contractor is educated of the communication methods in pre-construction meetings.

Maryland Department of Transportation also expressed that all strategies that would be applicable to normal incident management are also applicable to work zone incident management. It was also felt that Intelligent Transportation System strategies such as real-time incident and traffic information will improve incident response times and reduce traffic delays.

Minnesota Department of Transportation

Minnesota reported that there was a general list of steps that are currently being developed that will help guide the planning phase of a work zone incident management plan. In this development stage more formal plans are being created for incident management in work zones. Currently Minnesota as a freeway management system that covers 220 miles of urbanized area and the incident management specifications of the entire system are currently being used for incident management in work zones.

Educating the work crews was limited to a pre-construction meeting for the last major project. This meeting included all work crews involved and trained the work crews of the steps involved in the incident management. The meeting was very general and overall the contractors rely heavily in MnDOT’s normal response for incident clearance.

Communication is the same as that used in the normal traffic management center operations. No special communication is utilized for work zone incident management. The communication that occurs is regulated by an operational guideline handbook.

North Carolina Department of Transportation

There is no general list of steps established to help guide the planning phase of a work zone incident management plan. Although regular incident management teams are made aware of work zones and discuss changes to response that may be required due to the work zone. No plans are established for different construction phases and no steps are taken to educate contractors and work crews.

Ohio Department of Transportation

The Ohio Department of Transportation expressed that projects go through a process to implement a maintenance and traffic plan. In the case of a very large project that would affect motorists the most, meetings are held to discuss what could be done to minimize the impacts to the motorists and to help in assisting local emergency agencies respond. This is a time when a meeting with all agencies involved is held to discuss how to minimize response times as well as to shorten the length of time an incident will remain blocking lanes. During the meetings, it is stressed that time is critical in clearing the incidents from roadways and work zones. Work zone incident management plans are utilized, but only for projects in which lane closure are expected for 6 months or more.

Education of the work crews are left up to the main contractor performing the work and the DOT project engineer and inspectors.

Specific practices that have been the most effective in managing an incident in a work zone consists of having a predetermined check list in place to provide detour or alternate routes and a priority contact list for each work zone. In addition, on going contact with the construction contractors, project engineers and inspectors has been proven to be effective. Communication has been maintained and efficient through the use of a priority contact list and in the on going contact among involved agencies.

An innovative idea that was presented by the Ohio DOT was the possibility of allowing construction contractors to use their construction equipment to move vehicles that were involved in an incident from the traveled lanes to a safer location in order to open lanes in the shortest amount of time possible.

Texas Department of Transportation

A general list of steps established to help guide the planning phase of a work zone incident management plan is not used. Incidents that occur in work zones are treated the same as normal incidents other than the fact that Texas Department of Transportation construction personnel are alerted. As well, no plan is established for different phases of a construction project.

Contractors and work crews are not aggressively educated in the process. They are available for support but have no active role in traffic management.

The most effective practices in managing an incident in a work zone is said to be coordination with construction personnel.

Steps that are taken to ensure the most efficient lines of communication among all agencies involved when an incident occurs are established and maintained are the use of common communications, assessment of handling of major incidents, and constantly improving the plan.

An innovative idea of strategies and procedures that may advance the effectiveness of a work zone incident management plan is to utilize work zone configuration that is designed for the traveling public instead of for the contractor's convenience.

WORK ZONE INCIDENT MANAGEMENT PLAN CHECK LIST

The check list devised is a result of a literature research as well as feedback received from professionals in the field. It outlines a basic structure of steps that can be followed in creating a work zone incident management plan. The check list is divided into four different steps: Covering the Pre-Plan Necessities; Identifying Systems, Delegating Responsibility, and Setting Protocols; Specializing the Plan; and Assessing Quality and Effectiveness of the Plan.

The “Covering the Pre-Plan Necessities” portion of the check list is designed to outline the steps that need to be taken in order to begin the entire process. A management structure is described and the process in order to organize the structure is outlined.

The “Identifying Systems, Delegating Responsibility, and Setting Protocols” portion of the check list outlines the steps that need to be taken and the issues that must be addressed throughout the design phase of the work zone incident management plan. This step outlines the various processes that need to be planned and protocols that need to be set for application of the work zone incident management plan.

The “Specializing the Plan” portion of the check list is the most important portion in the design phase of the work zone incident management plan. In this step, scenarios resulting from the occurrence of commonly incurred incidents are discussed and step by step lists are made and documented for each incident. These commonly incurred incidents are applied to each phase of a construction project since different phases of construction present different provisions that must be made. The actual work zone incident management plan will be documented throughout this step.

The final step outlined in the check list is labeled “Assessing Quality and Effectiveness of the Plan.” This step includes various Measures of Effectiveness (MOE’s) that can be used to assess and monitor how well a work zone incident management plan works based on past experiences. It also outlines necessary tasks that must be completed following the occurrence of every major incident to ensure the work zone incident management plan is consistently being measured for performance.

Presented in each of the following sections is the respective portion of the work zone incident management plan check list that was developed from the information acquired through the literature search and the survey conducted in accordance with the objectives. Following each portion of the check list is a discussion of each step outlined in the check list and special considerations that should be taken into account in each stage of development of a work zone incident management plan. A complete work zone incident management plan check list can be found in its entirety, without additional explanation, in Appendix B, Work Zone Incident Management Plan Check List.

Step #1: Covering the Pre-Plan Necessities

The preliminary stage of assembling the work zone incident management plan is important to the completeness of the plan. The first step will primarily be on setting up the management structure that will be the foundation of management throughout the planning, design, and operation of a successful work zone incident management plan.

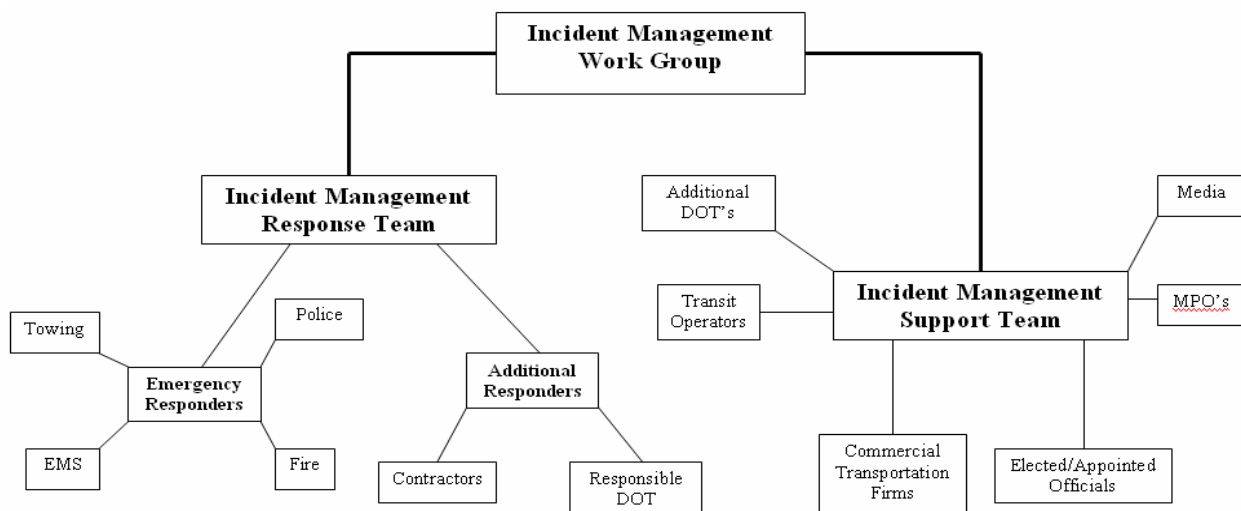
In an attempt to create an organized management structure, it is proposed that a Work Zone Incident Management Work Group be created. As depicted in Figure 2, two separate teams will make up this Work Zone Incident Management Plan Work Group: the Incident Management Response Team and the Incident Management Support Team.

Table 3. Step #1 of Check List

Step 1: Covering the Pre-Plan Necessitates	
☐	Develop preliminary Work Zone Incident Management Work Group • Develop list of involved agencies • Establish communication with a representative for each agency • Meet with all representatives
☐	Define Work Zone Incident Management Response Team • Meet with Work Zone Incident Management Response Team • Set-up training sessions for the Work Zone Incident Management Response Team
☐	Acquire necessary general information about project • Project beginning/ending dates • Number and dates of different phases of construction • Project plans • Incident location system • Additional required information

The Incident Management Response Team consists of the “active” members of an incident management plan that are directly responsible for performing tasks once an incident occurs. Examples of members of the Incident Management Response Team are the emergency medical responders, fire/rescue, police, towing services, the transportation agencies, responsible site contractors, HAZMAT, etc.

The Incident Management Support Team consists of agencies and groups that are not necessarily directly responsible for tasks once an incident occurs but can contribute to the information gathering and drafting of an incident management plan. Example members of the Incident Management Support Team are local Metropolitan Planning Organizations (MPO's), transit agencies, commercial transportation firms, media outlets, etc.

**Figure 2. Team Management Structure**

Under this section of the check list an initial “kick-off” meeting is recommended to be held with the entire Work Zone Incident Management Work Group. This meeting will be used to identify the two different teams and identify the importance and responsibilities of the Work Zone Incident Management Group as a whole. A contact list should be developed from all in attendance at the meeting. The group should be inquired of additional members that need to be included in the development of the work zone incident management plan and those members need to be contacted.

A separate meeting should be held during this phase of the check list with the Work Zone Incident Management Response Team. During this meeting training sessions should be scheduled with each agency. The training sessions will be held for several different reasons. Each agency will be informed of the hierarchical responsibilities of each agency, as well as their own. Jurisdictional boundaries and conflicts should be addressed during this training session as well. Other topics of discussion at the training sessions are: the method, accuracy, and timeliness of communication, identifying the key authoritative individuals at incident site, and expected roles and responsibilities of each agency.

Following all initial meetings and training sessions a complete contact list should be assembled. This contact list should consist of individuals to contact for each agency with multiple contact numbers. The list should be developed to aid all involved personnel once an incident occurs in making contact with the various agencies.

In addition, the preliminary stage will be used to acquire all the necessary information that will be needed in the design phase of the work zone incident management plan. Information such as the project beginning/ending dates, number and tentative dates of different phases of construction, project plans, if mile marking signs will be throughout the work zone, and any other information the Incident Management Work Group decides is necessary at this phase in the design is some of the information that will be gathered in this phase. Acquiring all the necessary information prior to beginning the design of the plan will save time and will help the design phase to run more smoothly and will ensure that the plan will be as organized and complete as possible.

Step #2: Identifying Systems, Delegating Responsibility, and Setting Protocols

In this section, general points are presented that need to be addressed and identified early in the drafting phase in order that the plan is designed to given specifications and is tailored to the needs of the particular work zone project. This part of the incident management plan will be the most important portion of the plan. It is crucial that each portion of this section be given an extensive amount of time and planning in order to ensure all systems and protocols run smoothly in conjunction with one another as well as individually. Funding and resources are always an issue and need to be taken into account in this phase of the work zone incident management plan.

Before determining what systems are to be put in place goals of the system(s) need to be defined. The goals will have an impact on what system(s) is chosen and will serve as measures of effectiveness (MOE's) once the work zone incident management plan is implemented and in use.

Detection and Verification

Systems for detection and verification need to be considered based on cost to benefit ratios. Detection and Verification of incidents in the past has relied heavily on 911 calls. Though this method may be effective as a means of detection, there is a possibility for extreme latency involved that would adversely effect the overall time it will take to return the roadway to normal flow. Relying on motorists to detect an incident may be the cheapest means of detection the reliability may be low enough that the potential benefits of another system could justify the cost. A system that is commonly used is the installation of Closed Circuit Television (CCTV) cameras throughout the work zone. Though these systems may be expensive, they have the ability to considerably cut critical response time thus the benefits received may

Table 4. Step #2 of Check List

Step 2: Identifying Systems, Delegating Responsibility, and Setting Protocols	
☐	Set goals expected of the plan
☐	Identify special provisions associated with different phases of construction
☐	Identify potential alternate routes
☐	Identify detection system • Determine most efficient means of detection for available funding • Draft installation plans for detection system
☐	Identify verification system • Determine most efficient means of verification for available funding • Draft installation plans for verification system
☐	Set protocol for response • Identify initial respondents • Identify the crucial information initial respondents must relay • Determine how information will be relayed to other agencies • Define key response players
☐	Set protocol for incident site management • Set chain-of-command • Create guidelines
☐	Set protocol for traffic management • Set chain-of-command • Identify required equipment • Identify available equipment • Identify where additional equipment will be stored • Define available support (i.e. flagmen, work crews, etc.) • Define alternate route plans • Define emergency vehicle access plans
☐	Set protocol for motorist information management • Set chain-of-command • Identify required equipment • Identify available equipment • Define methods of communication
☐	Set protocol for clearance • Determine if and what towing agreements will be established • Determine drop sites and accident investigation sites • Identify pertinent information required by towing agency • Determine what/where equipment will be on site available for use
☐	Set protocol for recovery • Determine how long diversion should remain in place based on queue • Determine most efficient means for re-opening the roadway

out-weigh the costs incurred. Another commonly utilized system for detection and verification is the roaming service patrol. This is the process of having service patrols in the field at all times roaming specified areas. This system could prove especially beneficial for work zones given the limited

boundaries of a work zone. Many different systems can be reviewed and their benefits can be assessed with the help of the Traffic Incident Management Handbook for the USDOT.(3)

Response

A protocol for response to an incident needs to be set in this portion of the design phase of the work zone incident management plan. When considering a response protocol it would be very beneficial to specify who and/or what agency will always initially respond to an incident. This elected official/agency will be trained and informed of the necessary information that will need to be relayed and to whom the information will be given for it to be disseminated and relayed to the respective agencies. The person(s) who will disseminate the information and distribute it will be referred to as the dispatcher. The dispatcher can be located at a local TMC, but this is not necessary. Only certain information is necessary for different agencies, the dispatcher will be the “middleman” and be responsible for getting only the relevant information to the relevant agencies. This should minimize the time and confusion involved, and prove efficient, in getting the correct equipment and personnel to the site without exposing too many agencies to unnecessary information.

The dispatcher will also be responsible for notifying various agencies that an incident has occurred and it may be possible that their services/resources may be needed. These agencies must then be “on stand-by” and ready to act at any point necessary. The dispatcher will also have a list of additional agencies that have the possibility of being contacted but will not generally be contacted in the occurrence of an incident such that their contact information is readily available should their services/resources be needed. Following the clearance of the incident the dispatcher is responsible for contacting all agencies on “stand-by” and inform them the incident has been cleared.

On-Site Management

The on-site management portion of the check list refers to all the management structures that need to be established for different processes involved once the necessary agencies, personnel, and equipment arrive at the site. This portion is divided into three different process that need to be managed: incident site management, traffic management, and motorist information management. It is important that a manager be elected for each specific process that will oversee all activities and serve as the responsible official of the process. Each process will involve many different agencies that will together serve as a team. The manager will serve as a contact person, organizer, and mediator for each team. Each manger is expected to be in contact and coordinate with the other two managers involved in the process.

Incident Site Management Incident site management refers to the all the management that needs to be conducted at the immediate site of the incident. Of all the processes listed, this process will be the most difficult to manage. Many different agencies will be required and present, in a small area, conducting many different duties and this manger must oversee that all duties are being conducted without “stepping on toes” or duplicating duties in an organized fashion while keeping safety as a primary concern. This manager will also be expected to relay all information necessary to the dispatcher. This information includes additional equipment required, additional personnel required, status of activities at the scene, etc.

Traffic Management Traffic management refers to all processes involved in regards to the diversion of approaching motorists in accordance with pre-specified plans. Example duties this manager will be in charge of will be implementing the diversion plans, implementing alternate route plans, and ensuring emergency access routes remain accessible.

Equipment for traffic management may be required in addition to the equipment already in the field for the work zone. Equipment such as additional construction barrels, construction cones, traffic flares, potentially required traffic control signs, etc. It is important to have this equipment readily accessible if not stored in the field in order to safely conduct the traffic management portion of the work zone incident

management plan. Specific standards are set for managing traffic through work zones on high speed facilities that should also be followed as closely as possible in managing traffic in the instance of an incident. Therefore, additional traffic management equipment may be required in order to safely divert traffic to the desired route. If equipment is to be stored in the field, the location and the type of equipment must be made common knowledge among all agencies that may be involved with this process in the work zone incident management plan.

Motorist Information Management The motorist information manager will be responsible for communicating crucial information to approaching motorists. This manager becomes especially important if any type of intelligent transportation system is in place, namely any system that involves changeable message signs. This manager will be responsible for what messages will go up, when they will go up, and at what location they will go up. In addition this manager will be responsible for getting portable signs into position and additional equipment into place if necessary.

Equipment for motorist information management includes portable changeable message signs, overhead dynamic message signs, highway advisory radio equipment, etc. Motorists who are at the site need to be informed of the conditions as well as motorists approaching the site and motorists who may be planning a trip through the site need to all be warned of the conditions at the site. One of the means of warning motorists, in particular approaching motorists and motorists who may be planning a trip through the site, of the conditions at the site will be through the media. Therefore, it is important to develop a strong working relationship with various media outlets and to educate them of various aspects of the work zone incident management plan. It is especially important to have strong communication and strong relationships with the media if none of the above listed on/near-site equipment is available for the project.

Clearance

The clearance portion of the check list details certain aspects associated with the clearance of the incident that need to be considered. Towing agreements are commonly utilized and should be seriously considered in the clearance of an incident within a work zone. These towing agreements can consist of multiple towing agencies that are rotated upon use. These agreements may be beneficiary in dealing with work zones because of the unique case that the general location where the towing agency will be required is already defined by the boundaries of the work zone. Towing agreements can be made with response time in mind when dealing with work zones.

Another technique that has been utilized and proven effective is the use of drop sites. Drop sites are locations where disabled vehicles can be re-located, off the roadway, and where crash investigations can be conducted. Due to the constraints a work zone creates, it is not uncommon that if single vehicle stalls within the work zone a traveling lane is blocked as a result. Obviously the severity of blocked lanes is compounded if a severe accident occurs within a work zone. If these drop sites are planned for each phase of construction and are set in the construction plans, then there will always be one or more areas that are designated and can serve as a refuge area that can be utilized in order to minimize the clearance time of incidents, thus their resulting congestion.

Recovery

The recovery portion of the check list is included to ensure that traffic is allowed to resume travel through the work zone in a safe and efficient manner. When a diversion is made, a plan needs to be discussed specifying how long the diversion should remain in place based on the queue build up from the incident. In addition, the most efficient means for re-opening the roadway need to be addressed and all personnel (namely the traffic manager) need to be trained of the steps to be taken and when they need to occur.

Step #3: Specializing the Plan

Once all the preceding sections have been completed and all the systems, methods, and protocols are identified, all the necessary information for putting the Work Zone Incident Management Plan together has been collected. The next step in the process is to assemble the work zone incident management plan. This will be done by creating a series of steps to follow once an incident occurs and documenting these steps. The steps documented in the initial portion of this phase need to be general. These are the steps that need to be followed every time an incident is to occur. The general portion of the work zone incident management plan will mainly encompass the steps to be taken in the detection and verification portions as well as a few steps of the response portion of the plan. This will make up the main portion of the work zone incident management plan.

Table 5. Step #3 of Check List

Step 3: Specializing the Plan	
☐	Apply incidents most commonly incurred to different phases of construction
☐	Identify specific emergency routes for access along work zone for each phase
☐	Outline required steps for on-site management for each incident
☐	Outline required steps for clearance for each incident
☐	Document required steps for each incident analyzed

Following the formation of this general structure, the specialized structure of the plan needs to be formed. This will be done by analyzing different types of incidents that commonly occur and documenting the courses of action that need to be taken in each case with the specific work zone and a specific construction in mind. Specializing this portion of the plan will customize the plan such that it is tailored to the constraints and needs of the work zone. This portion of the plan needs to remain flexible as a result of the inability to plan for every possible situation that may arise.

Step #4: Assessing Quality and Effectiveness of the Plan

This portion of the check list will be used as a means to determine how well the work zone incident management plan actually works. These steps help to establish measures of effectiveness of the Incident Management Plan. Once a major incident occurs an assessment needs to be taken of how the plan performed. Once this assessment is made changes and additions need to be made according to the needs of the plan.

The “Plan in Action” portion of this section is section is included to ensure the plan is constantly being monitored for performance. The goals set in step #2 should be utilized as MOE’s for this portion of the check list. Average times should be calculated for detection, verification, response, clearance, and recovery times and compared to the goals set for each. If any of the processes is not meeting the goals that were initially set, and assessment of the system needs to be made and solutions need to be identified and incorporated.

All functions of on-site management also need to be assessed. While devising MOE’s for this portion of the check list might be a bit arbitrary, an assessment of the functionality needs to be made. Means by which these processes can be assessed should be established for each work zone incident management plan and regularly monitored for functional effectiveness.

Table 6. Step #4 of Check List

Step 4: Assessing Quality and Effectiveness of the Plan	
☐	Assess the plan in action • Does average detection time meet goal set • Does average verification time meet goal set • Does on-site management function as planned • Does average response time meet goal set • Does average clearance time meet goal set • Does the recovery take the least amount of time possible
☐	Conduct the follow-up necessities • Plan frequent meetings with Incident Management Response Team • Set several meetings with Incident Management Work Group • Conduct debriefing meetings within one week of major incidents

Follow-Up Necessities

Within this section of the check list, courses of action that need to be taken regularly with the members of all teams in order to maintain the most effective and up to date incident management plan possible are outlined. Regular meetings with the Incident Management Response Team need to be conducted. In addition, debriefing meetings need to be held with the Incident Management Response Team within one week of the occurrence of a major incident. This meeting will be utilized to identify specific aspects of the plan and processes that were conducted which failed or were lacking in effectiveness. Those issues should then be addressed and the incident management plan should be revised in order that those issues are not encountered in the future. Additional meetings with the entire Incident Management Work Group need to be set. These meetings do not need to be as often but are still crucial throughout the duration of the construction project.

APPLICATION OF WORK ZONE INCIDENT MANAGEMENT PLAN CHECK LIST

The check list was developed and sent to James P. Reynold, an Area Manager that currently oversees all incident management activities in a major construction project along a 45 mile stretch of I-95 running through Palm Beach County in Florida. Mr. Reynold reviewed the check list and provided comments regarding where he felt special considerations may need to be taken into account based on his experience in the field. Several comments have been incorporated into the check list such as the addition of setting goals for recovery time and monitoring the level of effectiveness of the recovery process. Also reflected in the check list as per Mr. Reynold's comments, is the consideration of pre-specifying drop zones throughout the length of the work zone. Other comments Mr. Reynold provide that were not incorporated into the check list, in the essence of time comments, are further discussed in this section of the report. These comments have been provided with regards to the work zone incident management plan check list reflected specific issues that have been confronted in the field.

Mr. Reynold expressed that it is extremely important to begin the process of designing a work zone incident management plan early. The designers of the incident management plan need to be informed of and included in the design phases of the construction project. If the designers of the incident management plan are included in the designing phases of the construction project, it is more likely that the construction plans will be designed with the motoring public in mind rather than designed simply for the convenience of the contractors. The crucial input that can be provided by the incident management plan designers help ensure that the constraints and special provisions, created by the work zone, can effectively be

accommodated in the work zone incident management plan. This could be beneficial especially in the process of identifying specific drop sites, designating alternate routes, and identifying emergency vehicle access routes. It is important that a high level of collaboration be involved in these various processes such that the construction project designers take into consideration and possibly design the plans with the safety and needs of the motoring public in mind.

Another important point made was to impress the importance of the input and involvement of the various agencies to the work zone incident management plan. Through past experiences it was expressed that many different agencies at times take on the mind set of “what’s in it for me?” The most important consideration that must be emphasized to the agencies that have a reluctance of being involved is that the work zone incident management plan will be designed not only with the safety of the motoring public in mind but especially with the safety of the incident responders safety as a first order of importance. Statistics show that there is a high casualty rate from secondary incidents among traffic responders.

A final suggestion made by Mr. Reynold was to possibly add a third team to the Work Zone Incident Management Work Group that exclusively focuses on policy making or possibly change the name of the Work Zone Incident Management Support Team to the Work Zone Incident Management Policy Team. There are a seemingly countless number of agencies involved in the process of designing a work zone incident management plan as well involved in the implementation of a work zone incident management plan. Each of these different agencies has their own set of policies. When these agencies are required to work together as a team and each of the agencies incorporate their own set of policies the overall list of policies involved in the process may become overwhelming and some policies among different agencies may conflict or contradict one another. It would be the objective of the policy team to collaborate with each of the various agencies and determine all policies that may be involved and incorporate all the different policies into an overall set of policies for the Work Zone Incident Management Work Group. By developing an overall set of policies specifically for all agencies involved in the design and implementation of a work zone incident management plan, that reflect the policies of all the agencies, will help to ensure the implementation of the work zone incident management plan is expedient and runs as smoothly as possible.

CONCLUSIONS

Findings from the survey conducted show that many agencies currently rely on general freeway incident management plans when managing incidents that occur within work zones. While general freeway incident management plans are quite inclusive of the steps that need to be addressed throughout the implementation of an incident management plan, there are special considerations and provisions that occur as a result of a work zone, that are not often explicitly addressed when a general incident management plan is applied to an incident within a work zone. In the report many such considerations are discussed and accounted for in the final check list.

The check list was developed from the research conducted in this report in an attempt to create a structured outline by which professionals can follow. The check list will aid in the development of a complete and effective work zone incident management plan. Due to the wide variety of occurrences as well as the extensive list of various agencies that may be involved in the planning and operation of a work zone incident management plan, no check list can ever be complete. As a result, this check list is simply a starting point, upon which future research and additions should be, and need to be, continually added.

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APPENDIX A

INTERVIEW QUESTIONNAIRE

To date, a considerable amount of research has been conducted with regards to general incident management on freeways. Likewise, a considerable amount of research has been conducted on work zone management and the effects a work zone has on a freeway system. But what happens when an incident occurs within a freeway work zone? Many situations are created that are not addressed in a general incident management plan. Although some areas of a general freeway incident management plan may be the same, there are many aspects of a work zone that necessitate a special incident management plan as opposed to simply applying any “general” freeway incident management plan.

The purpose of this survey is to gather information on the state-of-the-practice throughout the United States of the use and procedures of work zone incident management plans. The information gathered will be synthesized in order to create a list of practices. From this list of practices a structured check list will be created aiding agencies in the development of an efficient and inclusive work zone incident management plan.

Please respond to the following questions as they relate to your practices and return your survey results to Michael Hofener via e-mail: m-hofener@ttimail.tamu.edu or by fax at (979) 845-4872 ASAP. If you have any questions about the survey please contact me via the e-mail address above or by telephone at (979) 845-9882. The survey can also be conducted by telephone. If you would prefer this method, please let me know and we can set a time to discuss the survey.

Thank you for your time and information. Your input will be very valuable to this research!

- Is there a general list of steps established to help guide the planning phase of a work zone incident management plan?
- For each work zone, as well as for each construction phase, is a plan established defining the steps to properly manage an incident if one were to occur?
- What measures, if any, are taken to ensure the contractors/work crews are educated in the steps they need to take if an incident were to occur?
- What specific practices have you found to be the most effective in managing an incident in a work zone?
- In your work zone incident management plan, what steps are taken to ensure the most efficient lines of communication among all agencies involved when an incident occurs are established and maintained?
- Do you feel a check list that structures the most important steps in the development of an incident management plan within a work zone would be useful?
- Do you have any innovative ideas of strategies/procedures that, to your knowledge, are not currently practiced but may advance the effectiveness of a work zone incident management plan?
- Is there any other information and/or contacts you feel might be valuable to this research?

APPENDIX B

WORK ZONE INCIDENT MANAGEMENT PLAN CHECK LIST

Step 1: Covering the Pre-Plan Necessitates	
☐	Develop preliminary Work Zone Incident Management Work Group • Develop list of involved agencies • Establish communication with a representative for each agency • Meet with all representatives
☐	Define Work Zone Incident Management Response Team • Meet with Work Zone Incident Management Response Team • Set-up training sessions for the Work Zone Incident Management Response Team
☐	Acquire necessary general information about project • Project beginning/ending dates • Number and dates of different phases of construction • Project plans • Incident location system • Additional required information
Step 2: Identifying Systems, Delegating Responsibility, and Setting Protocols	
☐	Set goals expected of the plan
☐	Identify special provisions associated with different phases of construction
☐	Identify potential alternate routes
☐	Identify detection system • Determine most efficient means of detection for available funding • Draft installation plans for detection system
☐	Identify verification system • Determine most efficient means of verification for available funding • Draft installation plans for verification system
☐	Set protocol for response • Identify initial respondents • Identify the crucial information initial respondents must relay • Determine how information will be relayed to other agencies • Define key response players
☐	Set protocol for incident site management • Set chain-of-command • Create guidelines
☐	Set protocol for traffic management • Set chain-of-command • Identify required equipment • Identify available equipment • Identify where additional equipment will be stored • Define available support (i.e. flagmen, work crews, etc.)

☐	· Define alternate route plans · Define emergency vehicle access plans
☐	Set protocol for motorist information management · Set chain-of-command · Identify required equipment · Identify available equipment · Define methods of communication
☐	Set protocol for clearance · Determine if and what towing agreements will be established · Determine drop sites and accident investigation sites · Identify pertinent information required by towing agency · Determine what/where equipment will be on site available for use
☐	Set protocol for recovery · Determine how long diversion should remain in place based on queue · Determine most efficient means for re-opening the roadway
Step 3: Specializing the Plan	
☐	Apply incidents most commonly incurred to different phases of construction
☐	Identify specific emergency routes for access along work zone for each phase
☐	Outline required steps for on-site management for each incident
☐	Outline required steps for clearance for each incident
☐	Document required steps for each incident analyzed
Step 4: Assessing Quality and Effectiveness of the Plan	
☐	Assess the plan in action · Does average detection time meet goal set · Does average verification time meet goal set · Does on-site management function as planned · Does average response time meet goal set · Does average clearance time meet goal set · Does the recovery take the least amount of time possible
☐	Conduct the follow-up necessities · Plan frequent meetings with Incident Management Response Team · Set several meetings with Incident Management Work Group · Conduct debriefing meetings within one week of major incidents

MICHAEL HOFENER

Mr. Hofener is a Research Associate at the Texas Transportation Institute (TTI) Center for Transportation Safety and is currently pursuing his Masters of Engineering degree in Transportation Engineering at Texas A&M University. He has received his B.S. in Civil Engineering from the University of Oklahoma and is currently working on his M.S. in Civil Engineering at Texas A&M University.

Mr. Hofener has spent accumulatively 2 years working for a Traffic Engineering Consulting firm. The scope of his project involvement included, but not limited to, traffic impact analyses, planning and in field acquisition of traffic data, intersection and roadway design, as well as computer aided drafting and included work in over 5 different states.

Currently, Mr. Hofener is working for the Center for Transportation Safety division of the Texas Transportation Institute. While at TTI, Mr. Hofener has aided in data acquisition and research for several different projects. He served as an assistant on the following completed projects: Assessment of Safe Routes to School (SRS) Projects for the Traffic Operations Division of TxDOT and Pavement Surface Elevation Changes in Highway Construction Work Zones as Contributing Factor to Motorcycle Crashes, as well as projects currently ongoing such as rural ITS deployment research and crash reduction factors as related to safety improvement projects.



EXAMINATION OF THE APPLICATIONS OF REMOTE SENSING TO TRAFFIC FLOW AND LEVEL OF SERVICE ESTIMATES

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SUMMARY

One of the most critical tasks for traffic engineers is the accurate estimation of traffic flow variables such as speed, volume, and density. These variables are often used as inputs to planning and operations studies. Ground based technologies such as inductive loop and magnetic detectors provide engineers with an inexpensive means for obtaining this data. However, these detectors only estimate data for single points on the roadway. When traditional ground detectors are combined with aerial imagery, a more accurate estimate of how the roadway system is performing as a whole can be obtained.

Remote sensors can be used to estimate a wide variety of traffic flow variables. The type of remote sensing looked at in this paper refers to aerial imagery from planes, helicopters, and uninhabited aerial vehicles (UAVs). Still photography and video footage are reduced manually to obtain roadway measures of effectiveness such as speed, volume, density, travel times, queue spillback, and level of service. Remote sensing experts, past users of remote sensing, and traffic management center operators were contacted to develop a methodology for using aerial imagery. Once the methodology was developed, it was sent to an expert panel for review and comment. The methodology for using remote sensing to estimate traffic flow variables includes the following tasks:

- Select Site
- Identify Traffic Applications
- Identify Image Resolution
- Select Aircraft
- Determine Field of View
- Calculate Flight Altitude
- Select Sampling Interval
- Collect Data
- Reduce Data

Remote sensing may be used to obtain data on any roadway of interest to the traffic engineer, however only a handful of sites are practical from an economic perspective. Aerial imagery is a feasible alternative for city-wide corridors, remote locations, hazardous locations, and high-incident roadways.

Although remote sensing is cost-effective if used in the above situations, there are several major issues that must be resolved before this technology becomes commonplace in Department of Transportation and traffic engineering firms. Excessive time and money are required to manually reduce data, which adds to the disutility of using aerial imagery. However, researchers are focusing on developing automated data reduction technologies, which would decrease costs and provide users with real time traffic flow information. Experts believe automated technology will be available within the next five years. Another hurdle is the high cost of aircraft. Plane and helicopter rental costs are high, however uninhabited aerial vehicles (UAVs) may be able to provide a cheaper alternative. Once air restriction issues associated with uninhabited aerial vehicles are resolved and these aircrafts are available for use, the total cost of remote sensing will significantly decrease. Although remote sensing technologies are expensive at present, it is important to note that all manner of microscopic and macroscopic traffic variables can be derived from the imagery. This can be contrasted with a typical ground-based sensor that may only give average speeds and flows.

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INTRODUCTION

The transportation community is well aware of the growing roadway congestion problem in the United States. As the population continues to increase, this problem will only continue to get worse. However, as intelligent transportation systems (ITSs) and their applications continue to grow, this issue may be mitigated. In particular, remote sensing is a new technology that has been showing excellent potential to transportation engineers.

Remote sensing is defined as the use of technology through waves, laser scan, or reflected light at a distant location to facilitate information exchange. There is a need to improve the accuracy of traffic flow data, as these variables are often critical inputs to planning and operations studies. Remote sensing technology can provide sufficient resolution to sense vehicle locations and movements across broader spatial scales than traditional methods. The use of remote sensing for obtaining traffic flow measurements is examined in this report (Average Annual Daily Traffic, density, and speed) and level of service estimates for signalized intersections and freeways. The evolution of remote sensing in the transportation field is examined first. A methodology is given later in this report to enhance the use of remote sensing technologies to transportation planning studies.

RESEARCH OBJECTIVES

The goal of this research was to develop a methodology for using remote sensing for estimating traffic flow data. Several objectives were identified in order to achieve this goal. These research objectives were:

- Identify, examine and catalog available remote sensing technologies;
- Identify how remote sensing is being used to obtain traffic flow data and level of service estimates;
- Develop a methodology for using remote sensing for obtaining traffic flow variables based on literature review and traffic management center officials' feedback; and
- Validate methodology with an expert panel of transportation professionals.

SCOPE

Aerial imagery from airplanes, helicopters, and uninhabited aerial vehicles was researched by the author. The research was limited to the applications of remote sensing to traffic flow data and level of service estimates. Other applications of remote sensing, such as chemical emissions and roadway construction were not addressed.

STUDY DESIGN

A work plan was developed to aid the formulation of the remote sensing methodology. Five tasks were performed in this research project.

Literature Review

A literature review was conducted to gather information regarding remote sensing. Past research studies and field tests were reviewed to inform the author of the current state of the art for estimating traffic flow parameters using remote sensing.

Interviews with Remote Sensing Experts

Remote sensing experts and former users of aerial imagery in the transportation community were contacted to aid the research process. The objective was to clarify any issues related to the use of remote sensing. Telephone and electronic surveys were conducted with these personnel to gather more information about their experiences with these systems. The survey questions are included in Appendices A and B. These individuals were asked a series of questions on the following topics:

- Cost of using remote sensing technologies, as compared to traditional methods of estimating traffic flow and LOS;
- Problems associated with using remote sensing technologies for the applications mentioned above;
- Current and future research on the area of interest;
- The accuracy of remote sensing data, as compared to traditional methods of data collection; and
- Data collection time using remote sensing.

Interviews with Traffic Management Center Operators

The author informed several traffic management center personnel on the benefits of remote sensing. Feedback was obtained on the practicality of applying remote sensing to their current practices. A sample questionnaire is provided in Appendix C. Information obtained from the survey included:

- Traffic management centers' current practice to collect traffic flow data and estimate LOS;
- Level of satisfaction with data accuracy and time for data collection;
- Cost of current practices;
- Problems with current practices; and
- Feasibility of using remote sensing to enhance or replace existing methods to estimate traffic flow data and LOS.

Develop Methodology For Using Remote Sensing

A methodology was developed for using remote sensing based on the feedback from the questionnaires. This methodology includes a set of tasks users of remote sensing must follow to obtain traffic flow information effectively. The methodology also identifies situations where remote sensing is a feasible alternative for estimating traffic data.

Verify Methodology

An expert panel was contacted to review the methodology. The individuals gave feedback on the methodology and identified positive and negative aspects associated with the results.

BACKGROUND

History of Remote Sensing Use in Transportation

Remote sensing has been used to obtain traffic flow information for over fifty years. In 1947, Greenshields took pictures from a blimp every two seconds at altitudes of between 2000 and 3000 feet for traffic analysis. He found many applications of his data including: origin, destination, and bottleneck identification; accident studies, and road capacity estimations (1). Other scientists continued research in this area in the 1950s, 60s, and 70s to measure flow, speed, acceleration, headways and platoon dispersion. However, in the 1970s, research halted because of the large costs and time associated with

data collection and reduction. In the 1980s work was done in Japan using automatic video processing. However, they encountered problems detecting vehicles due to occlusion and shadows.

Recently, the United States Department of Transportation (USDOT) Research and Special Programs Administration (RSPA) and the National Aeronautics and Space Administration (NASA) collaborated to establish the National Consortia on Remote Sensing in Transportation (NCRST) with funding under the Transportation Equity Act for the 21st Century (TEA-21). This research, with a focus on traffic flow information, is described later in this report.

Traditional Practice of Estimating Traffic Flow Variables

The accuracy of traffic flow estimates is limited by the precision and capabilities of the traffic sensor used for acquiring the data. Most traditional means of determining these parameters provide near-continuous temporal coverage only at a particular point in space, making it impractical to monitor the entire roadway network. Enhanced spatial coverage is provided by aerial platforms (See Figure 1), giving the traffic engineer a better understanding of how the roadway is operating. Aerial sensors provide added flexibility by permitting the use of a single aerial sensor at several locations.

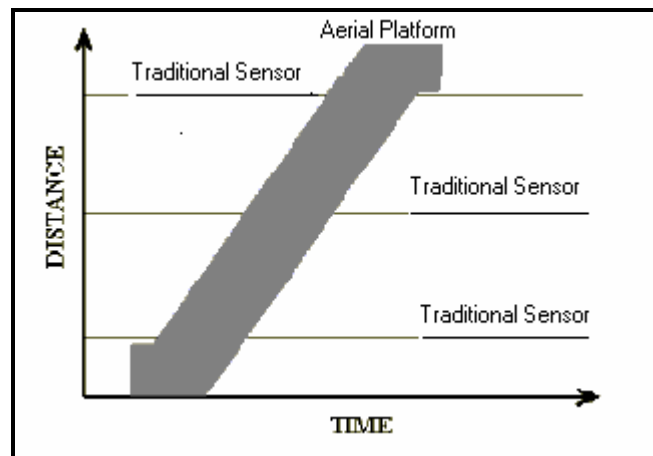


Figure 1. Comparison of Spatial Coverage Between Traditional and Aerial Sensors (2)

Along with enhanced spatial coverage and added flexibility, sensor maintenance can be performed off-road without affecting the flow of traffic (3). A brief description of common ground based detectors is provided in the next section.

Inductive Loop Detectors

Inductive loop detectors are the most widely used sensors for vehicle detection. An inductive loop detector consists of a loop of wire embedded in the pavement and connected to a control box. When a vehicle passes over the loop, the inductance is reduced, which causes a detection to be signaled in the control box. There are two types of loop detectors: single and double loops. Single loops have one trap, which is used for vehicle counts and lane occupancy measurements (3). A double trap system uses the second trap to measure the vehicle's speed, assuming the distance between the two traps is known.

There are two primary disadvantages to using inductive loop detectors: they can only be installed in good pavements and they are sensitive to installation techniques. Older pavements can be unstable, and in northern states, pavement can weaken by freeze-thaw cycle. This may result in pavement movement that

can stretch or break wires and connections, causing the loop to malfunction (4). Many loops also fail as a result of mishandling during the installation process, as unskilled technicians install the sensor poorly.

Piezoelectric Detector

A piezoelectric sensor consists of a long strip of piezoelectric material enclosed in a protective casing. It is embedded in the pavement, as a vehicle passes over the sensor, it is compressed, producing a voltage and the vehicle is detected. Piezoelectric detectors are accurate vehicle detectors, however they do not detect the presence of a stationary vehicle unless it stops with its wheels on the detector. One disadvantage of these detectors is a lack of durability (5).

Magnetic Detector

Magnetic detectors are in the form of probes that operate on the principle of a vehicle disturbing a magnetic field, similar to inductive loop detectors. Active and passive types exist. An active magnetic detector, or magnetometer, measures the change in magnetic field caused by the passage of a vehicle. A passive detector measures the change in flux of the earth's magnetic field caused by the passage of a vehicle. These detectors only measure moving vehicles, and cannot be used as presence detectors (3).

Microloop Detector

Microloop detectors are similar to inductive loop detectors in that they are made up of coils of wire embedded in the roadway. The wire detectors conduct a charge if activated. An electrical current induced by the charge is measured and recorded as a presence. Microloop detectors have the same disadvantages as inductive loop detectors in that they must be installed in good pavement and are sensitive to the installation process (5).

Photoelectric Detector

Photoelectric devices consist of two components, a light emitting source and a light detector. If the light source is blocked, a vehicle is detected. A major disadvantage to this sensor is that the light source and detector must be completely unobstructed except for vehicle passage. Fog and precipitation can create errors in detection by blocking or scattering light prior to detection (5).

Infrared Detector

There are two types of infrared detectors, active and passive. Active infrared detectors operate by illuminating the detection zone with infrared energy emitted by a light emitting diode or laser diode. Vehicles passing through the detection zone disrupt the signal and a detection is recorded. Disadvantages include malfunctions due to fog, shadows, and precipitation. Passive infrared detectors sense heat emitted by passing vehicles (3). Unlike active infrared detectors, these sensors do not emit any energy of their own. Disadvantages include malfunctions during hot weather conditions (5).

Radar Detector

Microwave radar detectors operate by utilizing a beam that is directed toward the detection zone and reflected back to the device. The device measures rebound time of the waves to obtain vehicle speed (3). They can be placed either above or alongside the roadway for easy maintenance.

Ultrasonic Detector

Ultrasonic detectors are similar to radar detectors in that they detect vehicles through reflected waves. However, ultrasonic detectors measure sound waves, while radar detectors measure microwaves. These

types of sensor are widely used in Japan. A disadvantage of the detector is that ambient noise can affect the accuracy of traffic data (5).

Video Image Detector

Video image sensors utilize a camera and video image processors to detect vehicles. When vehicles cross the detection zone, their presence is detected. Software packages allow travel time and density measurements to be obtained (5). The primary disadvantage of these detectors is their high installation cost.

REMOTE SENSING APPLICATIONS TO TRAFFIC FLOW

There are many remote sensing applications to traffic flow. Before these applications are described, an understanding of a few basic remote sensing concepts and definitions is necessary. Once these concepts have been introduced, a description of remote sensing equipment is provided, followed by a description of how traffic flow variables can be estimated using aerial imagery.

Image Scale

Image scale is the ratio of a distance on the image to the same distance on the ground. The scale must be selected well in advance of data collection (2). A tradeoff exists between image detail and spatial coverage; as the scale of an image increases, the field of view (FOV) decreases. The aerial photographs shown in Figure 2 display this tradeoff. Scale is defined for digital images in terms of pixels, with units of pixel/ft or ft/pixel.

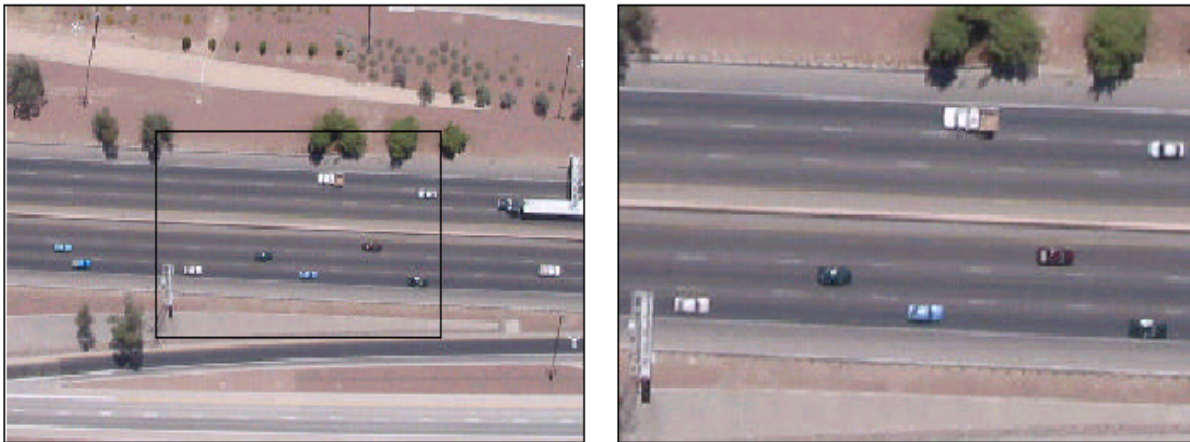


Figure 2. Aerial freeway images. Left: scale 1:2000, FOV 500 ft. Right: scale 1:1000, FOV 250 ft (2)

Field of View

An image's FOV is defined as the spatial coverage in the direction of interest. Large FOVs are applicable for intersection operations, density estimates, and travel time measurements (2). For intersection studies, a large field of view enables the camera to include the back of the queue and to track large platoons. Other applications such as instantaneous speed measurements track only one or a few vehicles, thus a smaller field of FOV is feasible. In the case of digital and still cameras, if the camera is placed perpendicular to the ground and a scale is defined, the FOV can be computed using equation 1. For

example, if the resolution is 1 meter per pixel and the scale is 1:2000, then the field of view is 2000 meters.

$$FOV_D = \frac{\text{resolution}}{\text{scale}} \quad (1)$$

where,

FOV_D = field of view of the digital image (length)

Resolution = sensor resolution (pixels)

Scale = image scale (pixels/length)

The scale for analog cameras can vary with the size of the image, hence a different equation is needed (equation 2).

$$FOV_A = \frac{H}{f} * D \quad (2)$$

where,

FOV_A = field of view of the analog image (length)

H = Flight altitude (length)

F = Focal length (length)

D = Image size in one dimension (length)

Flight Altitude

Flight altitude is a function of the focal length of the camera and the field of view. For an analog camera, altitude is computed solving equation 2 for H (flight altitude). Camera manufacturers often provide the “equivalent 35mm focal length”, or the focal length required to maintain the same image properties as if the sensor was 35 mm (6). By using the equivalent 35 mm concept, flight altitude for digital cameras can be calculated using equation 3. For example, if the field of view is 2000 meters and the equivalent 35 mm focal length is 50 mm, then the flight altitude required is 2858 meters.

$$H = \frac{FOV_D * f_{35}}{35mm} \quad (3)$$

where,

H = Flight altitude (length)

FOV_D = Field of view of the digital image (length)

f_{35} = Equivalent 35 mm focal length (length)

Geo-referencing

An image is geo-referenced if its elevation and ground location is known in a coordinate system. The precision needed depends on the application being used. For example, traffic density measurements require only the difference in elevation between the aircraft and the ground, and a general knowledge of the location (approximate mileposts are often sufficient). Applications that require the most precise geo-referencing are those that track individual vehicles, such as instantaneous speed studies (6).

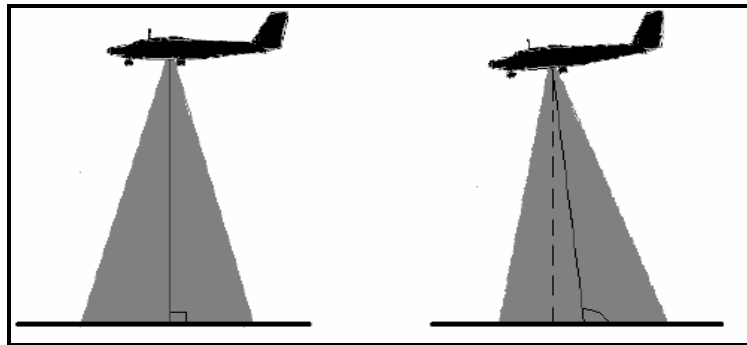


Figure 3. Effect of Pitch on Ground Coverage (6)

In all there are six factors that determine the location of the ground region covered in an image: X, Y, and Z coordinates; and, roll, pitch, and yaw (See Figure 4). Roll refers to the angle of the wings relative to the horizontal, pitch to the angle of the nose relative to the horizontal (see Figure 3) and yaw to the bearing angle of the plane. . When the nose of the aircraft forms an angle with the horizontal, the area covered is different from that if it were perpendicular to the ground.

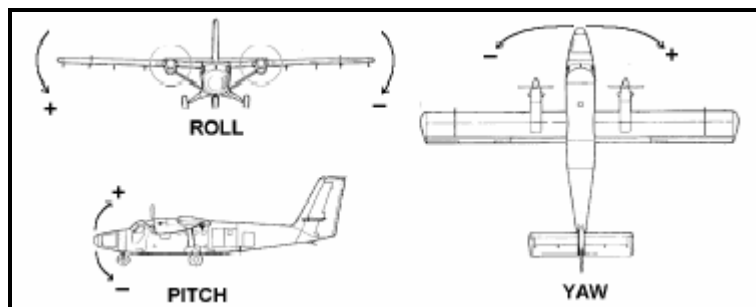


Figure 4. Schematic of Roll, Pitch, and Yaw (6)

Sampling Interval

The sampling interval is defined as the time interval elapsed between frames. As altitude and scale should be determined before a flight, the sampling interval is also a critical factor to data accuracy. It is often desirable to have overlap between successive frames in order to identify the location of one image relative to another (3). The sampling interval depends on the field of view, aircraft speed and traffic application. The sampling interval is proportional to the field of view and inversely proportional to the speed of the aircraft. For still cameras, a technique must be defined to automatically capture frames at the desired interval. Some recent digital cameras contain software capable of taking images at fixed time intervals. If a video camera is used, sampling interval is not an issue, because they can record up to 30 frames per second. Space based sampling can also be used, where instead of using time intervals, images are taken at locations of interest.

The traffic application is also critical to data precision (See Table 1). Instantaneous measures of vehicles require smaller intervals than those of stopped vehicles. Distance measurements can be measured precisely even using small intervals. Time sensitive measures, such as speed and acceleration, require larger intervals. A smaller sampling interval should be used for smaller field of views and a larger interval for the higher end of the range. For traffic density measurements, the only requirement is that some overlap exists.

Table 1. Precision of Traffic Variables as a Function of Sampling Interval (3)

Time Interval	Distance	Dispersion	Headway Spacing	Speed	Time Headway	Acceleration
.5 sec	+	+	+	-	-	--
1 sec	++	++	++	+	+	-
2 sec	+	+	+	++	++	+
++ Good +Fairly good -Poor --Very Poor						

Equipment

Cameras

Digital and analog cameras are the two types of cameras used for data collection, and are classified based on type of data storage. Still digital cameras use memory cards to store data, while analog cameras have a limited number of photographs per film length. For digital cameras, the amount of memory needed to store an image is a function of image resolution and its format (2).

A camera must be chosen with proper resolution. Digital images are comprised of grids of color and light information, each box in the grid is called a pixel. For any ground image, more pixels means more detail. Image resolution is the ground distance shown in the image divided by the number of pixels used to cover that distance. For example, if the ground measures 1000 meters across an image, and the width of the image grid is 2000 pixels, then image resolution is .5 meters per pixel. Imagery is typically produced at resolutions of 1.25 to .2 meters per pixel (7). Higher resolutions take longer to acquire and process, which means higher costs.

Helicopter, Airplanes, and Uninhabited Aerial Vehicles

Traffic data are most commonly collected from either fixed winged planes or helicopters. Each aircraft has specific properties that make it more suited for different applications. There are two critical criteria when selecting one type of craft over another: minimum speed and cost (3). Helicopters are capable of hovering over intersections and flying at the speed of traffic. They are useful when more concentrated examinations of specific locations and vehicles are necessary. Helicopters can be used to measure intersection delay, arterial travel time, density, individual vehicle speeds and trajectories (8). Airplanes are suited to collect data quickly over broad areas. Fixed winged aircraft must fly at least 50 miles per hour. Thus, they are more suited to measure density on long stretches of freeway but impractical for following traffic on urban streets. Fixed winged planes are relatively cheaper than helicopters (See Table 2), so when all desired data could be collected from a fixed winged plane, they are generally the preferred option.

Another type of craft currently in test stages is the uninhabited aerial vehicle (UAV). These aircraft typically have a five foot wingspan and weigh between ten and fifty-five pounds but fold into a tube that is fifteen inches in diameter and four feet long for storage. UAVs are capable of operating autonomously and deliver video imagery and sensor data in real time (9). Compact ground stations containing a laptop personal computer are programmed by the user to perform desired tasks (10).

Table 2. Comparison of Aircraft Properties (6, 9).

	Fixed wing	Helicopter	UAV
Stall speed	47 knots (54 mph)	0	25 mph
Maximum speed	123 knots (141 mph)	115 knots (132 mph)	50 mph
Useful load	875 lbs	1400 lbs	1-2.5 lbs
New price	\$152,000 (approx.)	\$1,000,000 (approx.)	\$35,000-\$42,000
Used price	\$50,000 (1984 model, approx)	\$500,000 (1989 model approx.)	Unavailable
Rental cost	\$80-110/hr (without pilot)	\$400-600/hr (with pilot)	Unavailable

The PC has a moving map display showing the aircraft's speed and altitude in real time. Launch is possible by hand or catapult while landings occur on wheels. UAV's can fly up to 9,000 feet and at speeds of 25-50 miles per hour for a maximum duration of six hours. These systems cost between \$35,000-\$42,000, which includes aircraft, launch equipment, ground station, and standard sensors (See Figure 5).

Although UAVs are cheaper than traditional helicopters and planes, limitations exist to its applications for traffic data collection. Air space restrictions by the Federal Aviation Administration (FAA) limit UAV use. Current FAA standards assume an operator in the aircraft, however UAV manufacturers are working with the FAA to develop standards for this craft. Remote sensing experts believe once these air traffic issues are resolved, aerial imagery use will be much more appealing due to the low cost of UAVs (8).

**Figure 5. UAV Launch Device and Ground Station**

Estimation of Travel Time and Origin-Destination Matrices

Travel time is one of the most commonly used measures of effectiveness for roadways. Many techniques for travel time estimation exist, including floating car techniques, license plate matching, and using ground cameras to track vehicles. These methods provide the total travel time over a section of roadway, but do not give information on individual link travel times. However, obtaining accurate data at a reasonable price from these methods is a current issue that must be resolved. Aerial video can be used to identify problematic links, thus providing more detailed information.

In a study conducted at the University of Arizona, a helicopter was used to track individual vehicles as they progress through a street (3). Helicopter data were compared to ground measurements from a video camera at endpoints of road segments and from a test car. The ground camera gave the true travel time, as the aerial and test car data were compared to this true value. The aerial data was viewed on a television monitor while a technician recorded the time vehicles passed checkpoints. The results showed that the data obtained from aerial videos were closer to the true travel time than the test car.

Vehicles can be traced manually through aerial surveys, which leads to a direct estimation of origin-destination matrices. Travel time and turning movement estimates obtained from remote sensing would enhance origin-destination (O-D) estimates obtained from ground-based technologies such as loop detectors (11). Remote sensing provides a cost effective solution for these calculations. Consulting firms generate origin-destination matrices for \$10,000 to \$20,000 through manual tracing of vehicles, while an O-D matrix obtained from license plate matching typically costs \$40,000 or higher (12).

LOS Estimation

Signalized Intersections

Level of service for signalized intersections (See Figure 6) can be estimated using a helicopter or other aircraft capable of hovering over the intersection of interest (13). Before imagery is taken, one must determine the field of view and image scale required to cover intersection queues and identify individual vehicles. Once these parameters are defined, the procedure described below can be used to determine control delay and level of service (13).

1. The first step is to determine the intersection geometry and identify lane groups. Lane groups should be defined based on function.
2. After identification of intersection geometry, stopped vehicles must be counted on all approaches at regular time intervals. The sampling interval should be smaller than the green time for the shortest phase in the cycle, usually between ten and twenty seconds.



Figure 6. A Signalized Intersection in Tucson, Arizona (13)

3. The vehicles per lane group crossing the intersection during the study period must be counted from the imagery.
4. Stopped delay per vehicle should be calculated using equation 4.

$$sd_i = A * I * \frac{\sum_{j=1}^n V_{sij}}{V_i} \quad (4)$$

where,

sd_i = Stopped delay for lane group I (sec)

A = Empirical adjustment factor (.9 for still cameras, 1.0 for video)

I = Interval between stopped vehicle counts (sec)

V_{sij} = Number of stopped vehicles for lane group I in frame j (veh)

V_i = Departing vehicles for lane group I (veh)

n = Number of sampled frames

5. Following the methodology given in the Manual of Transportation Engineering Studies, control delay for a lane group can be approximated as 1.3 times the stopped delay as shown in equation 5:

$$di = 1.3 * sd_i \quad (5)$$

where,

d_i = Control delay for lane group i (sec)

sd_i = Stopped delay for lane group i (sec)

6. Once the control delay is determined, the level of service is identified from Table 3. The control delay is calculated as the average delay of all the lane groups in the approach divided by the volume of departing vehicles during the study period.

Table 3. HCM Control Delay (13)

LOS	Control delay (s/veh)
A	<10
B	>10-20
C	>20-35
D	>35-55
E	>55-80
F	>80

Freeways

The following methodology should be followed when computing freeway level of service from aerial imagery (2). An illustration of the process is shown in the flow chart (See Figure 7).

1. Determine field of view from equation 1.
2. A time based sampling strategy should be determined. In most cases it is desirable to have overlap between frames to determine the location of one image with respect to another.

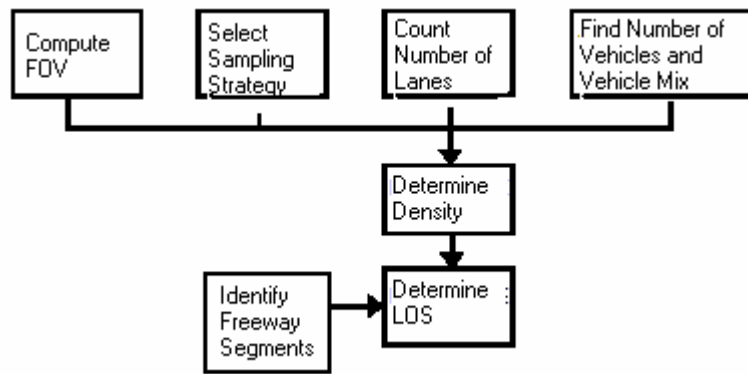


Figure 7. Freeway LOS Diagram (2)

3. Freeway segments should be divided into the following segments: weaving segments, freeway ramps and basic segments.
4. Count the number of lanes in each direction for each sample image.
5. Determine the number of vehicles and the vehicle mix, which can be counted directly from the image. It is necessary to convert the number of trucks, buses and recreational vehicles into passenger car equivalents using the HCM tables.
6. The traffic density can be calculated for a freeway segment using equation 6.

$$D = \frac{PC + T * E_T + RV * E_{RV}}{FOV * N} \quad (6)$$

where,

D = traffic density (pc/mi/ln)
 PC = number of passenger cars in the image (pc)
 T = number of trucks and buses in the image
 E_T = Passenger car equivalent for trucks
 RV = number of RVs in the image
 E_{RV} = passenger car equivalent for RVs (pc/veh)
 FOV = field of view of the image (mi)
 N = number of lanes in freeway segment

7. The level of service can be determined from Table 4.

Table 4. LOS Densities for Freeways (2)

LOS	Basic freeway segments	Weaving segments	Ramps
A	0-11	<10	<10
B	>11-18	>10-20	>10-20
C	>18-26	>20-28	>20-28
D	>26-35	>28-35	>28-35
E	>35-45	>35-43	>35
F	>45	>43	Demand exceeds capacity

SURVEY RESULTS

Expert Responses

Cost

Remote sensing experts were contacted to obtain additional information on remote sensing research. The first issue addressed was the cost to obtain remote sensing data. Data collection costs vary depending on aircraft selection, imagery resolution, and number of images required. The various costs associated with obtaining and reducing imagery are listed below (8):

- An archived satellite image costs approximately \$2000, which provides an 11 km x 11 km square on the ground for an instant in time.
- One hour in a rented helicopter costs approximately \$600 with a pilot.
- A low end uninhabited aerial vehicle costs approximately \$35,000-\$42,000.
- One hour in a rented airplane costs approximately \$200 with a pilot.
- Manual data reduction is \$10-\$12 per hour.

Once imagery is obtained, manual data reduction is necessary. Data reduction time depends on the measure desired. A still image from an airborne camera can be processed manually in a couple of hours, however video data may require several days' effort for any traffic parameter (8). The combination of data collection, reduction and analysis gives the total cost. One consulting firm provides aerial surveys for large cities at between \$100,000 and \$200,00 for 300 to 500 centerline miles of highway (12). These surveys include peak period patrols over selected corridors, while an expert photographs bottlenecks or key interchanges. Hour-by-hour maps are produced that show the extent and evolution of traffic congestion, along with report summaries on the underlying causes (7).

Although remote sensing technologies can be costly, it is important to note that all manner of microscopic and macroscopic traffic parameters can be derived from the imagery including: individual and average vehicle speeds, headways, densities, and delays (8). This can be contrasted with a typical ground-based sensor (loop detectors, road tubes) that may only give average speeds and flows. Due to the many applications of remote sensing imagery, it can be re-used for a variety of studies.

Problems with remote sensing

Another issue addressed in the expert surveys was the problems that exist with using remote sensing. A serious limitation that no one has been able to resolve is that of weather and daylight constraints (8). These factors have historically been known to cause aerial photographers to wait for clear weather, and therefore postpone planned flights. Daylight constraints can limit the amount of coverage area and number of run samples that can be obtained within the peak periods. Photographs taken during low light conditions can be more difficult to read than those during full daylight hours. A solution to these problems could be obtained through parts of the spectrum outside of visible light such as LIDAR, high resolution radar, and infrared sensing (8). However, these alternatives are all too expensive at present to be used for traffic applications.

Other hurdles to using remote sensing include cost and data reduction processing. The cost of obtaining and analyzing the imagery must be made reasonable for DOT's. There is also a need for image processing techniques that automatically reduce traffic data. Data is currently reduced manually, however an automated system equates to lower costs, as technicians would not need to be paid for several hours of labor. Experts believe these issues will be resolved within the next five years, as image processing techniques are on the verge of major breakthroughs and UAV's become more widely used (8).

Client Responses

Dowling Associates used aerial imagery as part of their work for level of service monitoring for the Santa Clara Valley Transportation authority in California. Density was estimated by manually counting vehicles on freeway segments. Travel speeds and traffic volumes were obtained using density-speed-volume equations calibrated for Santa Clara County conditions (14). They have been applying this method of data collection and reduction since 1997. Pre-1997 projects utilized floating car techniques to collect travel speed data and manual counts at select locations. This company decided to use remote sensing because it provides them with more data than can be provided at the same cost using traditional ground based methods. In addition, a physical record of the data collection (photographs) were made available after data reduction if any questions arise concerning it (14).

The North Central Texas Council of Governments was also contacted to share their experiences with past remote sensing projects. Using a fixed wing aircraft, the company took a photographic inventory of approximately 750 miles of highways during the peak morning and evening periods of travel in 1999 (15). Vehicle counts and the corresponding level of service for each of the roadways were determined, as well as vehicle classification. Other alternatives considered included floating car techniques for travel time data and manual vehicle counts. However, aerial photography was less expensive than these other solutions. Along with being cheaper than the other alternatives, the agency felt they could obtain a better feel for how the roadway system was operating as a whole in a shorter amount of time. The agency stated that there were no problems encountered during this study and plans to repeat the data collection effort this year (15).

Traffic Management Center and Department of Transportation Responses

Atlanta, Georgia

TMC officials in Atlanta, Georgia stated they are using video detection for their freeways (16). Through this method, video from black and white camera sensors is fed into processors, where it is analyzed for passing vehicles. The output from this process includes gap, headway, LOS, speed, counts, occupancy, and vehicle length data. These data are sent from each processor every twenty seconds to the TMC. Once at the TMC, the data are used to calculate travel times and feed data to their website. They have a web application that allows them to query historical traffic data and retrieve daily reports that show lane-by-lane volumes and average speeds on an hourly or 15 minute basis. The accuracy level of their data is good, as error rates are less than 5 percent. The primary source of error is large trucks, which occlude smaller vehicles, or get counted in more than one lane. Other issues include shadowing during dawn and dusk, and nighttime headlight glare. The cost of the system is rather expensive, processors range from \$30-50k each, and cameras are approximately \$5k (16). There are also additional costs for cabinets, poles, mounting hardware, fiber connections, and labor.

Colorado Department of Transportation

The Colorado Department of Transportation was also contacted for this study. They are currently using Automatic Traffic Recorders (ATRs), including weigh in motion stations (17). Short duration traffic volume and axle classification is generated by traditional hose technology. Continuous ATR for density, headway, speed, axle classification and volume use inductive loop and piezoelectric detectors. Problems encountered with this technology include decreased accuracy at times of maximum congestion (i.e. at low speeds or minimum headways). Other issues include poor road surface conditions, which can lead to problems with the intrusive detectors. A single Automatic Traffic Recorder installation for a 4-lane highway costs about \$20,000 on average. The total cost for CDOTs annual data collection is approximately \$250,000. Maintenance costs are difficult to estimate but are significant.

In addition to the methods described above, CDOT is also using radar equipment at three sites and intends to add more sites in urban locations (*17*). Radar units are used in locations where it is not feasible to install and maintain intrusive detectors and at locations where limiting their data to volume only is acceptable. They stated it is difficult to justify interrupting traffic at high volume locations for installation and maintenance of intrusive data collection equipment.

San Antonio, Texas

The San Antonio division of TXDOT has created an ITS system called Transguide to estimate speeds, volumes, and occupancy values in real time (*18*). Transguide uses cameras, fiber optics, and message signs to relay information to motorists. TMC officials stated they are satisfied with the accuracy of the data as well as their travel times displayed on dynamic message signs (DMS). No problems exist with their current system. They stated remote sensing could be considered if the quality of information and performance exceeded the existing system within budget constraints (*18*).

METHODOLOGY FOR USING REMOTE SENSING

A methodology is needed to inform transportation engineers of a set of tasks that should be followed in order to collect remote sensing traffic data effectively. Along with following the procedures included in this methodology, the user must also take into account factors such as weather and project budget. Remote sensing can also be useful for incident management verification, however further research must be conducted on this topic.

Task 1: Site Selection

The first task is to decide whether remote sensing is a feasible alternative for collecting traffic flow data. Locations where it is practical to use aerial imagery are discussed below.

Remote Locations

An important application of remote sensing technology is to collect traffic flow data in remote locations where ground sensors (inductive loop detectors, magnetic detectors) have not been installed. When combined with ground data, aerial imagery can provide extended roadway coverage that gives the traffic engineer an idea of how the roadway system is acting as a whole. Remote sensing imagery and data reduction costs can be compared to the cost of sending out ground crews to collect traffic data to these areas that lack permanent count stations. Aerial imagery can also capture both directions of travel on major roadways, while additional personnel and equipment may be required to collect data on the ground.

Hazardous Locations

Remote sensing prevents personnel from being exposed to potential traffic hazards. Installation of temporary ground sensors often exposes workers to traffic dangers, particularly at sites such as roadways that lack shoulders and busy interchanges. With remote sensing nothing has to be installed, maintained or removed.

City Wide Corridors

Aerial imagery is also useful for estimating flow variables on arterials and highways that run through densely populated cities. This data provides planners and traffic engineers with a better feel for how the highway system is operating as a whole. Bottlenecks and queue profiles can be created for problem areas such as highway side streets and freeway ramps that are typically difficult to obtain through loop detectors.

High Incident Locations

Roadway incidents often lead to bottlenecks that may not be characteristic of the facility. Incidents may skew traffic flow parameters. However, these uncharacteristic traits may be removed from flow estimates to obtain an accurate facility analysis using remote sensing technologies.

Task 2: Identify Traffic Applications

Once the traffic engineer has selected a site, the traffic application must be identified. Aircraft selection, field of view, and the sampling interval all depend on the traffic variables obtained from the remote sensing imagery.

Task 3: Identify Image Resolution

Image resolution should be selected depending on project budget. Higher resolution is more detailed and takes more time to process, so it is more expensive. Consulting firms offer image resolutions that range between 1.25 and .2 meters per pixel.

Task 4: Select Aircraft

The user must determine whether fixed wing planes or helicopters are appropriate. Helicopters are useful when more concentrated examinations of specific vehicles and locations are necessary. Helicopters are useful when measuring intersection delay, arterial travel time, and individual vehicle speeds. Airplanes collect data quickly and over broader areas. Fixed winged planes are suited to collect data over long stretches of freeway or city wide corridors.

Task 5: Determine Field of View

Once the resolution and aircraft are selected, field of view must be determined depending on the type of data required. Large fields of view may be required for intersection studies where it is necessary to track large platoons or to include the back of queues. Other applications that track individual vehicles may use a smaller field of view.

Task 6: Calculate Flight Altitude

Once the field of view has been determined, the flight altitude may be calculated. Flight altitude is a function of the equivalent 35 mm focal length and field of view.

Task 7: Select Sampling Interval

The sampling interval depends on the field of view, aircraft speed, and traffic application. A smaller sampling interval should be used for smaller fields of view and for instantaneous measures of traffic data. If the aircraft is traveling at a high speed, a smaller sampling interval may be required to capture the necessary footage. If a video camera is used, sampling interval is not an issue because they can record up to 30 frames per second.

Task 8: Collect Data

Once tasks one through seven are completed, traffic data may be collected. Sample size depends on project budget. However, it is recommended that data be collected on three weekday mornings and evenings during the peak hours. This assures weekend traffic will not create any data inconsistencies. Data should be collected on each roadway segment once an hour for two hours during the peak period.

The observer must remain alert, as an incident may alter traffic behavior. Imagery containing incidents should be discarded until full recovery has occurred, as they are often a primary source of data outliers.

Task 9: Reduce Data

After data collection, manual reduction is necessary to obtain the desired traffic flow variables. For long roadway segments, overlapping photos should be placed side by side so vehicles can be counted or traced.

Additional Considerations

Before investing in remote sensing imagery to collect traffic flow data, personnel and weather are two issues that must be addressed. It is vital to obtain well-trained persons to operate camera equipment, as they may be able to zoom in and prevent potential imagery problems such as shadow appearances. Poor weather can lead to flight cancellations, and also must be planned for appropriately in a project budget.

Other Applications

Another useful application of remote sensing is persuading public officials, often non-technical persons, to choose the proper allocation of funds. Aerial imagery can be useful on powerpoint presentations to show politicians where true problem areas exist.

Remote sensing can also be a viable solution to many other transportation problems. An aerial view of highway systems may be used to provide motorists with real time information on traffic conditions. Once a procedure to automate roadway measures of effectiveness is developed; information on travel times, speed, and congestion can be relayed to motorists via variable message signs.

With the emergence of UAVs, their quick take off ability makes them ideal for quick responses to transportation incidents. Their ability to transmit real time video footage would aid the determination of correct responses to traffic incidents.

VERIFICATION OF METHODOLOGY

The methodology described in the previous section was sent to five remote sensing experts for approval. Three of the experts responded to the methodology. They were asked to make comments and notify the author of any additions or changes they felt were necessary. The expert panel stated that the methodology was satisfactory and no changes or additions were necessary. The expert panel responses were provided by the following individuals:

- Greg Jordan, Skycomp Inc.
- Bill Cisco, Dowling Associates.
- Natelie Bettinger, North Central Texas Council of Governments

CONCLUSIONS

Remote sensing is a promising new technology that transportation engineers must become more familiar with. Aerial imagery has a variety of applications that if used in the scenarios mentioned in this paper, can be a practical and cost effective alternative to estimating traffic flow data. Current issues such as manual data reduction and cost still need to be resolved. However, once the air restrictions associated with uninhabited aerial vehicles (UAVs) are resolved the cost of obtaining aerial imagery will

significantly decrease. The focus of current research is on a procedure to automate data reduction procedures. Once these two major hurdles are overcome, remote sensing will become a much more feasible technology to implement.

ACKNOWLEDGEMENTS

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APPENDIX A: SURVEY FOR REMOTE SENSING EXPERTS

1. What is the approximate cost difference between existing technologies and remote sensing to estimate traffic flow parameters such as density, speed, VMT, AADT, and LOS?
2. What can be done about the problems of shadows and poor weather conditions? Is remote sensing still an applicable system to use in cities where poor weather conditions are the norm?
3. Are there any other major problems associated with using remote sensing to estimate these parameters?
4. Are traditional methods for estimating these parameters sufficient?
5. What is the accuracy difference between existing technologies and remote sensing?
6. What is the difference in data collection time?
7. Are there any other benefits to using remote sensing besides those mentioned above?
8. How can one assess the appropriateness of using remote sensing to obtain traffic flow information?
9. In what situations should remote sensing be used to estimate this information?
10. Are you aware of any research being conducted on using remote sensing to estimate traffic flow information?

APPENDIX B: SURVEY FOR FORMER AND CURRENT USERS OF REMOTE SENSING

1. Please describe the applications of remote sensing used in your past projects.
2. Were there any other alternatives other than using remote sensing that you considered for estimating traffic quality?

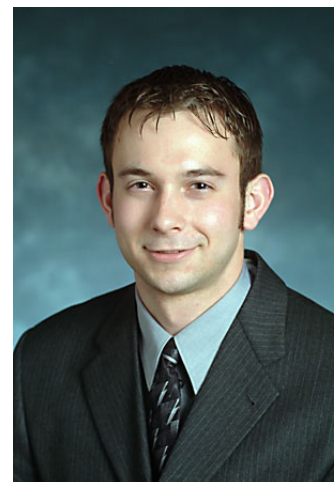
3. What was the cost difference between remote sensing and the other alternatives you considered?
4. Were any problems encountered from the remote sensing data you received? If so, please describe these problems.
5. Why did you choose remote sensing for your project as opposed to other alternatives of estimating traffic quality (if any)?
6. In what situations do you feel remote sensing is a viable alternative for estimating traffic flow parameters such as speed, density, and flows as opposed to more traditional methods?

APPENDIX C: SURVEY FOR TMC OPERATORS

1. How are you currently estimating traffic flow parameters such as density, speed, AADT, and LOS?
2. How do you conduct vehicle counts on side streets?
3. Are you satisfied with the accuracy of data you obtain using these traditional methods?
4. Are you satisfied with the data collection time?
5. How much do these methods cost?
6. Do any problems exist with the methods you currently use to estimate the above parameters?
7. Have you ever considered using remote sensing for these estimates?
If so, please describe the applications and state why you decided to use remote sensing instead of more traditional methods.
8. Would you consider replacing your current practice with remote sensing techniques?
If not what would it take for you to consider replacing your existing practice with remote sensing?

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INVESTIGATION AND OPTIMIZATION OF MOBILE SOURCE EMISSION MODELING METHODS

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SUMMARY

Agencies in most ozone non-attainment areas use a four-step travel demand model combined with the MOBILE emission model to estimate the regional mobile source emission inventory. The outputs from the travel demand models need to be post processed and adjusted to meet the Environmental Protection Agency (EPA) requirements for emission modeling. However, no detailed guidelines and standardized procedures are provided by EPA for estimating some crucial components (i.e. vehicle miles traveled (VMT) and speed) in emissions calculation. Differences in post process procedures and adjustment methods cause differences in emissions calculated.

Five ozone non-attainment areas were investigated for their practice of post process procedures and adjustment methods. The investigation showed that each of the five areas uses different methodologies to post process the travel model outputs and estimate the emissions. The application of spatial and temporal VMT disaggregating method was different for all five areas. In addition, each area uses different speed models for post processing the link speeds. The MOBILE6 is a major improvement over MOBILE5 by disaggregating the emission factors. However, the increased disaggregation creates difficulties for generating the same level of details in vehicle activity data.

This investigation provides the description of different practices in emission estimation. The potential non-attainment areas under the new 8-hour standard may use this information to start with their emission modeling. In addition, the EPA can use the findings to provide a more standardized procedure for emission estimation.

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INTRODUCTION

In response to the Clean Air Act of 1970, the Environmental Protection Agency (EPA) established National Ambient Air Quality Standards (NAAQS) for six criteria air pollutants with the goal of protecting public health and welfare. These six criteria pollutants are ozone (O_3), particulate matter (PM), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and lead (Pb). On-road vehicle emission is a major source of two of these criteria pollutants, namely O_3 and CO. Progress has been made in reducing emissions from motor vehicles since 1970, despite a more than doubling of vehicle miles of travel. However, challenges still exist. Based on monitored data, approximately 121 million people in the United States reside in counties that did not meet the air quality standards for at least one NAAQS pollutant in 2000 (1).

Ground level ozone is a noxious pollutant. However, ozone in the upper atmosphere (the “ozone layer”) occurs naturally and protects life on earth from harmful ultraviolet radiation. Ground level ozone is not directly emitted, but is formed by the reaction of oxides of nitrogen (NO_x) and volatile organic compound (VOC) in the presence of sunlight. In 1999, it was estimated that on-road vehicles produced 29 percent of all VOC emissions, 34 percent of all NO_x emissions in the US (2).

In order to regulate the NAAQS, the EPA designates the areas that do not meet the NAAQS as non-attainment areas. As of June 2003, there are 25 ozone non-attainment areas in the nation. Agencies in these ozone and other pollutants non-attainment areas must submit air quality plans, known as State Implementation Plans (SIPs), showing how they will attain the standards. If they fail to do this, they face the Clean Air Act required sanctions and other penalties, including possible loss of highway funds. Current ozone standard is 0.12 parts per million (ppm) concentration in one-hour time period. An area is in violation of the standard if it exceeds the concentration level for the specified time frame. For example, four exceedances of the one-hour ozone standard must occur over a three-year for a violation to occur. Figure 1 shows the current ozone non-attainment areas under the one-hour standard (3).

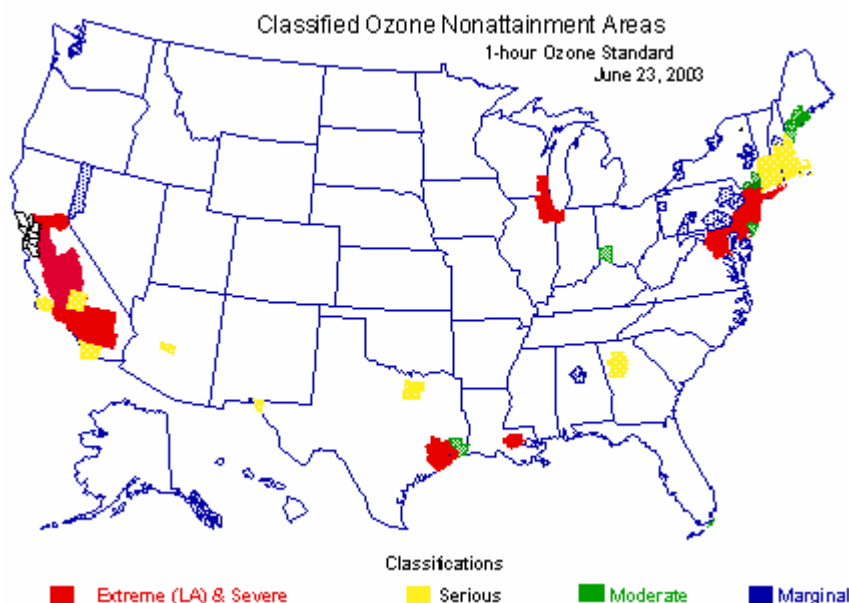


Figure 1. Ozone non-attainment area Map (one-hour standard)

In July 1997, EPA announced a new ozone standard. The new 8-hour standard is more stringent than the one-hour standard because the ozone concentration level is lowered to 0.08 ppm rather than the old 0.12 ppm. The new standard is expected to be implemented in 2003. Figure 2 shows the areas that currently

attain the one-hour standard, however will become the potential non-attainment areas or close to the non-attainment areas under the new 8-hour standard based on the monitored data from 1999 to 2001 (4).

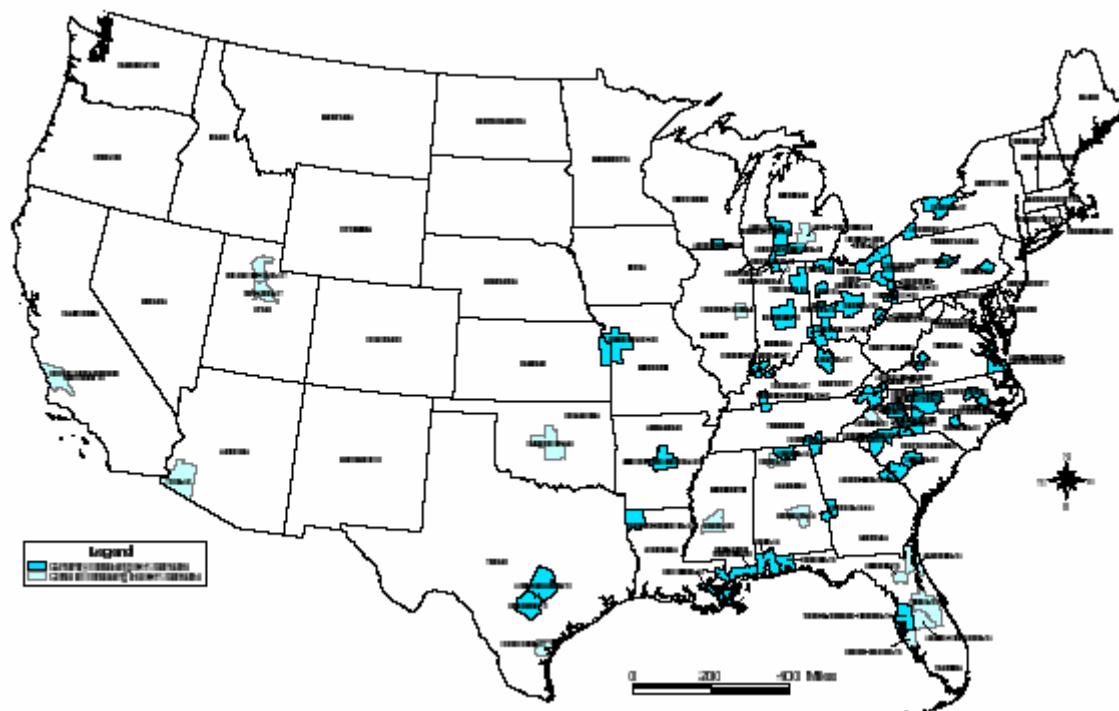


Figure 2. Potential additional ozone non-attainment area Map (8-hour standard)

PROBLEM STATEMENT

It can be seen from Figure 2 that the number of ozone non-attainment areas will likely increase substantially under the new standard. It, therefore, becomes increasingly important to be able to estimate the mobile source emissions as required by SIPs and to have some consistencies in modeling methods among the non-attainment areas.

Agencies in most non-attainment areas use a four-step travel demand model combined with the MOBILE emission model to estimate the regional mobile source emission inventory. The outputs from the travel demand model need to be post processed and adjusted to meet the EPA requirements for emission modeling. Currently, agencies in different non-attainment areas use different post process procedures and adjustment methods to suit their data needs. Differences in post process procedures and adjustment methods may cause differences in emissions calculated. An investigation in the state-of-the-practice emission modeling methods and an assessment in emission differences caused by different modeling methods are needed for EPA to regulate the mobile source emissions.

RESEARCH OBJECTIVES

The objectives of this research were to:

- Identify crucial components in the emission modeling procedure and required data inputs suggested by the EPA;
- Develop a summarized mathematical form for mobile source emission estimation methodology;

- Identify the state-of-the-practice modeling methods used in ozone non-attainment areas in the states; and
- Assess calculated emission differences caused by different modeling methods.

SUMMARY OF MOBILE SOURCE EMISSION INVENTORY

Of all of the sources of air pollution, only the emissions of some stationary sources are measured directly and continuously through instrumentation. Emissions from all other sources must be estimated in some fashion, including those from highway vehicles.

If every vehicle emitted the same amount of pollution all the time, one could simply multiply the emission rate (also called the emission factor) with the vehicle miles driven to estimate total emissions. However, the fact is that emission rates from all vehicles vary over the entire range of conditions under which they operate. These variables include air temperature, speed, traffic conditions, operating mode (i.e. cold start, warm start, steady cruising) and fuel. In addition, the vehicle fleet is composed of different generations, types of vehicles and their emission control technologies, each of which performs differently. This requires that the composition of the fleet (vehicle ages and types) must also be included in the estimation algorithm.

To quantify the emissions being released from vehicles on roads, emission factors for various vehicle types were developed and can be calculated using the MOBILE model. The MOBILE model was first developed as MOBILE1 in the 1970s, and has been periodically updated to reflect the changes in vehicle emission control technologies as well as applicable regulations and standards. MOBILE5, the state-of-practice in emission model, and MOBILE6, the newly released replacement of MOBILE5, are mandated by EPA for regional mobile source emission inventory studies in all the states of the US, except California. California uses the EMFAC model developed by the California Air Resources Board (CARB). The MOBILE model calculates average in-use fleet emission factors for various vehicle types and various conditions affecting in-use emission levels (e.g., ambient temperatures, average traffic speeds, gasoline volatility) as specified by the model user.

Four-step travel demand models are designed to estimate vehicle demand for an urban area at the link level. Because the travel model is able to estimate the link specified traffic volume for not only historic years but also future years, its outputs are desirable for emission modeling which estimates emissions for both historic and future years

The general approach that uses the travel demand model with MOBILE models for emissions estimation can be summarized by the author in Equation 1 and 2:

$$E_p = \sum_{i=1}^N \sum_{j=1}^T E_{ijp}^f * VMT_{ij} \quad \forall i = 1, \dots, N; \forall j = 1, \dots, T; \forall p = 1, \dots, P \quad (1)$$

$$E_{ijp}^f = \sum_{v=1}^V e_{ijpv}^f * w_{ijv} \quad \forall v = 1, \dots, V \quad (2)$$

Where:

E_p = total Emissions of the network for pollutant type p (grams);

E_{ijp}^f = composite emission factor of all vehicle types for pollutant type p corresponding to the average speed on link i for time period j (grams/mile);

VMT_{ij}	=	volume miles traveled on link i for time period j (vehicles/hour);
e_{ijpv}^f	=	emission factor of vehicle type v for pollutant type p corresponding to the average speed on link i for time period j obtained from MOBILE5 or MOBILE6 (grams/mile);
w_{ijv}	=	VMT percentage for vehicle type v on link i at time period j ;
N	=	number of links in the network;
T	=	number of time periods; and
P	=	number of pollutant types; and
V	=	number of vehicle types.

The most important data groups for emission estimation as shown in equation 1 and 2 are (1) emission factors, (2) link VMTs, (3) link average speeds, and (4) link VMT percentage for various vehicle types (VMT mix). Potential errors and inaccuracies in the emissions estimation also fall into these groups. Inaccuracies in emissions factors come directly from errors in applying the MOBILE model or from errors in the MOBILE emissions factor model. Errors in the MOBILE emissions factor model are the responsibility of EPA. Inaccuracies in VMT and speed result directly from errors or inaccuracies in the calibration or application of travel models or from deficiencies in the post assignment analyses of travel models. The focuses of this paper are not on the inaccuracies and differences in travel models where the VMT for emission modeling is obtained from, but on potential inaccuracies that come from the post process of travel model outputs.

VMT Estimation

To assist the agencies in non-attainment areas in meeting the requirements for emission inventory development, the EPA has provided the guideline for modeling mobile source emissions when using MOBILE4 and 5. The following adjustments to VMT are suggested by EPA (5).

- Highway Performance Monitoring System (HPMS) adjustment
EPA and US DOT both endorse the HPMS as the appropriate means by which to measure VMT, the travel model VMT need to be consistent in the aggregate with HPMS.
- Seasonal Adjustment
HPMS Annual Average Daily VMT should also be adjusted for seasonal effects. Since the VOC and NOx emission inventories are typical summer weekday inventories, VMT for ozone non-attainment areas should be adjusted to the summer season using the traffic counts data.
- Allocating VMT to Time of Day
It may also be necessary to allocate daily model VMT to each hour of the day or specific time periods. The recommended method of apportioning daily VMT to specific hours is to use the HPMS continuous traffic monitors data available within the Federal Aid Urbanized Area (FAUA).

The three adjustments are also applicable using MOBILE6. The newly released MOBILE6 provides the emission factors for each hour of the day, the only time of day adjustment is to allocate the VMT to 24 one-hour time periods instead of other aggregation of time periods (i.e. AM peak, PM peak, midday, overnight). MOBILE6 is still in the transition phase to replace MOBILE5 for mobile source emission inventory.

Some improvement has been made in estimating link volume within the travel demand model including estimating link volume for two different directions of a link and estimating link volume for different time

periods of the day. However, it is not an uncommon practice to have the daily non-directional trip assignment in the travel demand model.

Speed Estimation

In the travel demand models, the primary purpose of link average speed is to serve as a factor in assigning travel across the network. Speed is, therefore, primarily used as a measure of impedance to travel rather than a prediction of accurate travel characteristics. Emission estimation, however, requires both vehicle demand and speeds as inputs, with accurate and representative speed being a crucial factor for estimating emission factors.

Agencies in many non-attainment areas improve the speed estimation by employing a more realistic speed-flow curve (other than the traditional Bureau of Public Road (BPR) curve) or by using a post-processing speed model to compute more accurate speeds than what can directly be obtained from the travel model. Despite these efforts, vehicle speed estimation remains to be a weak link in emission estimation (6).

The average speed is a key input to the MOBILE model. However, it should be noted that both the MOBILE user guide and the EPA does not explicitly state the speed estimation method. There are opportunities to improve the characterization of speed within the travel models and within post processing. The report "Travel Model Speed Estimation and Post Processing Methods for Air Quality Analysis," TMIP, October 1997, provides a summary of various approaches to speed estimation (6). Since MOBILE is sensitive to speed, and since the impacts of proposed transportation projects and programs are often evaluated in terms of improved travel time, it is critical that speed be carefully handled within the travel models and within post processing applications.

The emission estimation procedure using a 24-hour non-directional travel demand model output can be illustrated by the author in Figure 3.

THE STATE-OF-THE-PRACTICE MODELING METHODS

Ozone non-attainment areas use a wide variety of practices in modeling travel demand and vehicle emissions. The major differences in emission modeling methodologies and travel demand modeling methodologies that are related to the emission estimation can be summarized into following categories:

- Does the area have a link-based travel demand model? What time periods are modeled in the travel demand model?
- Is the VMT adjusted for HPMS and seasonal fluctuation?
- Does the travel demand model have a directional or non-directional assignment?
- Is the speed post processed for emission estimation? If so, what speed model is used?
- How is VMT by vehicle type (VMT mix) developed?

Five ozone non-attainment areas were chosen randomly from the severe and serious ozone non-attainment areas in the country and investigated for different emissions estimation methodologies in terms of the above categories. These five ozone non-attainment areas are:

- Atlanta, GA (Serious Ozone Non-attainment Area)
- Washington, DC-MD-VA (Serious Ozone Non-attainment Area)
- Chicago-Gary-Lake County, IL-IN (Severe Ozone Non-attainment Area)
- Philadelphia-Wilmington-Trenton, PA-NJ-DE-MD (Severe Ozone Non-attainment Area)
- Providence (All Rhode Island) (Serious Ozone Non-attainment Area)

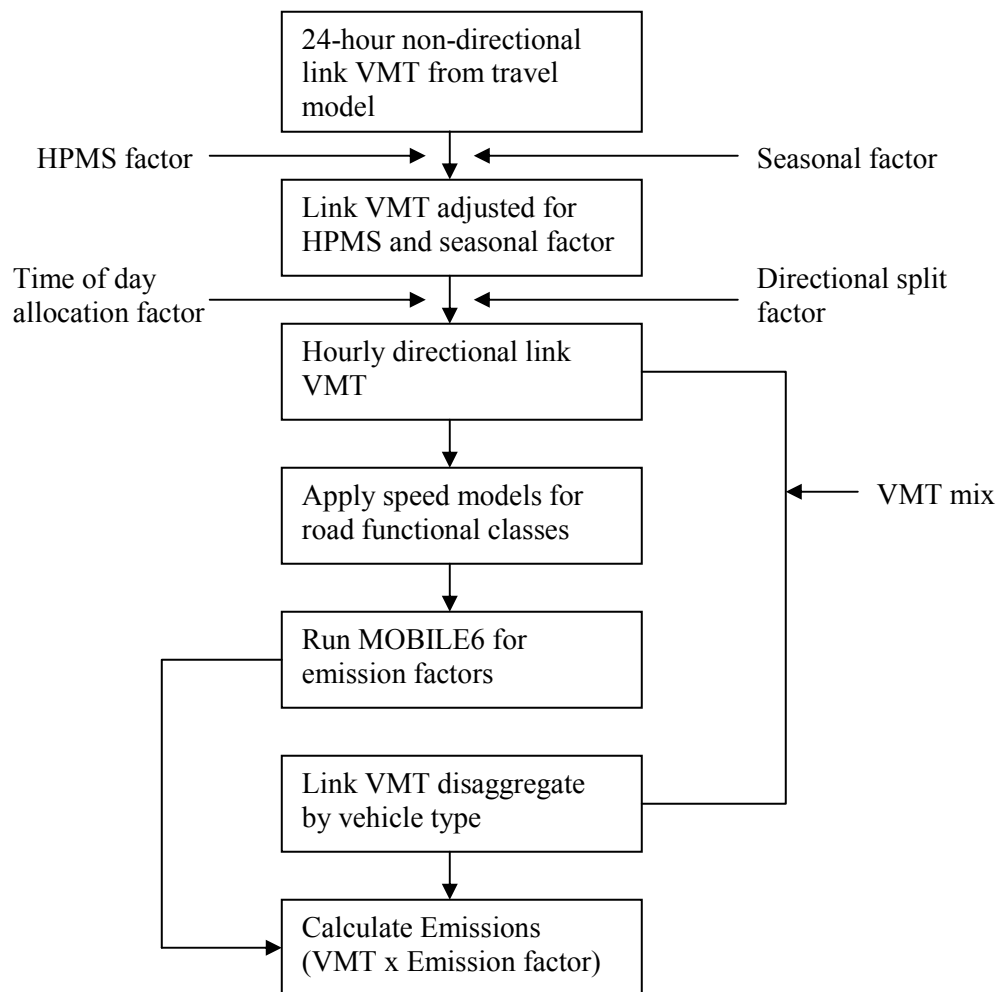


Figure 3. Vehicle Emissions Estimation Procedure

The investigation result can be summarized in Table 1. The modeling details for each of the five areas are explained in the following individual sections.

Atlanta, GA (Serious Ozone Non-attainment Area) (Z)

Link-Based Model and Time Period Modeled

To establish mobile source emission estimates for conformity analyses, the Atlanta Region Commission (ARC) used a traditional link-based procedure as an element of the travel demand model chain. Within the travel demand model, each vehicle trip that occurs during the course of the day is assigned to one of four time periods: the morning peak period (6:00 a.m. to 10:00 a.m.), the evening peak period (3:00 p.m. to 7:00 p.m.), the mid-day period (10:00 a.m. to 3:00 p.m.) or the nighttime period (7:00 p.m. to 6:00 a.m. the following day).

Directional Split

No directional factors were applied for emissions modeling purposes because in the network a two-way link was coded such that a separate traffic volume would be reported for each direction, i.e., if link X->Y is two-way, then a volume would be reported for the X to Y direction and the Y to X direction.

Table 1. Summary of Emission Estimation Methodologies

Ozone non-attainment areas	Link based model?	Time period modeled	Link directional split used?	Post process speed?	Speed model used	HPMS adjustment	Seasonal adjustment	VMT mix
Atlanta, GA	Link based model	6:00 - 10:00 a.m. 3:00 - 7:00 p.m. 10:00 a.m. - 3:00 p.m. 7:00 p.m. - 6:00 a.m.	No, directional link volume output from travel model	Yes	A lookup table that defines ratios of free flow time to congested time as a function of assignment group and V/C ratio	Yes	Yes	Based on the Highway Statistics data and default values in the Emission Inventory Improvement Program (EIIP) Volume IV
Washington, DC- MD-VA	Link based model	12 midnight – 6 am 6 – 7 am 7 – 8 am 8 – 9 am 9 – 10 am 10 am – 3 pm 3 – 4 pm 4 – 6 pm 6 – 7 pm 7 pm – 12 midnight	Yes, a set of traffic distribution factors were developed for the ten discrete periods of the day by the link's directional orientation toward the central downtown core of the District of Columbia	Yes	The MWCOG BPR curve is used for the speed calculation	Yes	No	Based on an estimate of the overall non-bus HDV VMT fraction as output from COG's travel demand model combined with county-specific registration distributions and diesel sales fractions and MOBILE6 default data on the VMT mix by vehicle type within the heavy and light-duty vehicle categories

Table 1. Summary of Emission Estimation Methodologies (Cont'd)

Ozone non-attainment areas	Link based model?	Time period modeled	Link directional split used?	Post process speed?	Speed model used	HPMS adjustment	Seasonal adjustment	VMT mix
Chicago-Gary-Lake County, IL-IN	Link based model	• 8:00 pm to 6:00 am • 6:00 am to 7:00 am • 7:00 am to 9:00 am • 9:00 am to 10:00 am • 10:00 am to 2:00 pm • 2:00 pm to 4:00 pm • 4:00 pm to 6:00 pm • 6:00 pm to 8:00 pm	No, directional link volume output from travel model	Yes	Modified BPR curves that have been used at Chicago Area Transportation Study (CATS) and other agencies for many years	Yes	No	The formulas used are based upon the method developed by IEPA for the 1996 15% ROP SIP
Philadelphia-Wilmington-Trenton, PA-NJ-DE-MD	Link based model	Hourly	No, directional link volume output from travel model	Yes	Modified Creighton, Hamburg surface arterial equations	Yes	Yes	Calculated from algorithms using a combination of MOBILE6 default percentages and PENNDOT truck percentages from roadway data
Providence (all Rhode Island)	Link based model	Peak time (hourly v/c >0.7) Off-Peak time period	No, total link volume used	No	No	Yes	Yes	Developed on state vehicle registration data

HPMS and Seasonal Adjustment

To ensure the accuracy of the travel demand model, the highway assignments were validated by the ARC against Georgia DOT's HPMS data for the year 2000 – HPMS data being the national standard and primary benchmark of VMT for travel demand modeling purposes. Another check was performed for screen line volumes measured by Root Mean Square Error (RMSE), which provides the average error level at each level of volumes.

HPMS adjustment factors were developed based on average daily, summer-adjusted HPMS VMT counts for the year 2000. The HPMS adjustment enables link-based VMT to be reconciled to observed summer time travel conditions at the functional class level. The following equation was used to calculate the HPMS adjustment factors:

$$\text{HPMS Adjustment Factor}_i = 2000 \text{ HPMS VMT}_i / 2000 \text{ MODEL VMT}_i$$

Where:

i = HPMS functional class

To determine the “2000 HPMS VMT,” the ARC calculated average daily VMT for the year 2000 by the 12 HPMS functional classes for each of the 13 non-attainment counties using Georgia DOT's Office of Information Services (OIS) 445 report. The 445 report has information on mileage and VMT by route type and road system and contains county specific state route, county road and city street mileage and VMT divided by functional classification. Average daily VMT was then summer-adjusted using latest available summer adjustment factors provided by the OIS. Summer-adjusted VMT by county and functional class were aggregated to total VMT by HPMS functional class. To determine “2000 Model VMT,” a pivot table report was run within the emissions model to aggregate link-level VMT to the HPMS functional class level. Table 2 reflects 2000 HPMS and MODEL VMT by functional class, along with the HPMS adjustment factors calculated by the ARC.

A look-up function was applied within the emissions model to determine, based on the HPMS functional class coded for each link, the appropriate adjustment factor needed to reconcile model VMT to HPMS data. The same set of factors was applied to each network year modeled for the conformity analysis.

Post-Process Speed and Speed Model Used

The link speeds were post processed for emissions modeling. Revised volume-delay functions were initially developed using the results of empirical studies on roadway volume and delay distributions in urban areas over a 24-hour period. The research is published in an FHWA document entitled “Development of Diurnal Traffic Distribution and Daily, Peak and Off-peak Vehicle Speed Estimation Procedures for Air Quality Planning.” This research quantifies how rural and urban roadways distribute peak hour traffic to other hours of the day under heavier traffic volumes, and the implications that this has on the average operating speed of the roadway. The Volpe Research Center report, “Roadway Usage Patterns: Urban Case Studies,” was also used as reference during initial development of the volume-delay functions.

Once the initial volume-delay functions were developed, the functions were modified to reflect local Atlanta travel conditions using data collected from two recent speed studies conducted in the fall of 2000 and the fall of 2001.

The volume delay curves were translated into the emissions model within a look-up table that defines ratios of free flow time to congested time as a function of assignment group and v/c ratio. The ratio of free flow to congested flow is referred as a speed function. The speed functions allow a reduction in time

Table 2. HPMS Adjustment Factors

HPMS Functional Class	2000 HPMS Data	2000 Model Data	Adjustment Factor
Rural Interstate	5,822,597	9,398,698	0.63
Rural Principal Arterial	3,680,932	3,054,389	1.21
Rural Minor Arterial	3,929,654	2,437,145	1.61
Rural Major Collector	3,619,184	3,052,298	1.19
Rural Minor Collector	1,228,002	946,288	1.30
Rural Local	3,424,895	11,948,389	0.29
Urban Interstate	37,825,822	40,420,998	0.94
Urban Other Freeway	5,765,979	2,712,102	2.13
Urban Principal Arterial	10,398,680	12,568,864	0.83
Urban Minor Arterial	22,101,606	16,374,946	1.35
Urbanized Collector	7,466,254	6,415,413	1.16
Urbanized Local	15,412,042	13,402,392	1.15

to be coded for each combination of v/c ratio and assignment group. The congested flow speed was calculated by multiplying the free flow speed on a link by the appropriate speed function. An example follows:

Link X was coded as assignment group 15. The link distance is 0.20 mi, the free flow speed is 36 mph, the congested speed output from the travel demand model is 22.65 mph, and the v/c ratio is 0.719. Based on an assignment group of 15 and a v/c of 0.719, the speed function is 0.650. (Excel's look-up function uses the highest v/c ratio without going over, thus this is the value for a v/c ratio of 0.7.) Based on these parameters the post-processed congested flow speed is 36 mph x 0.650 or 23.40 mph. This was the value used in emissions calculations.

The AM Peak period speed flow curve by facility type is shown in Figure 4.

VMT Mix

The ARC developed VMT mix based on the Table VM-4 of 1999 Highway Statistics. The table has the distribution of annual vehicle distance traveled by vehicle type. The default values in Table 2-1 from the EIIP Volume IV: Mobile Sources, Chapter2: *Use of Locality-Specific Transportation Data for the Development of Mobile Source Emission Inventories* were used to further disaggregate the vehicle types to what are in the MOBILE5.

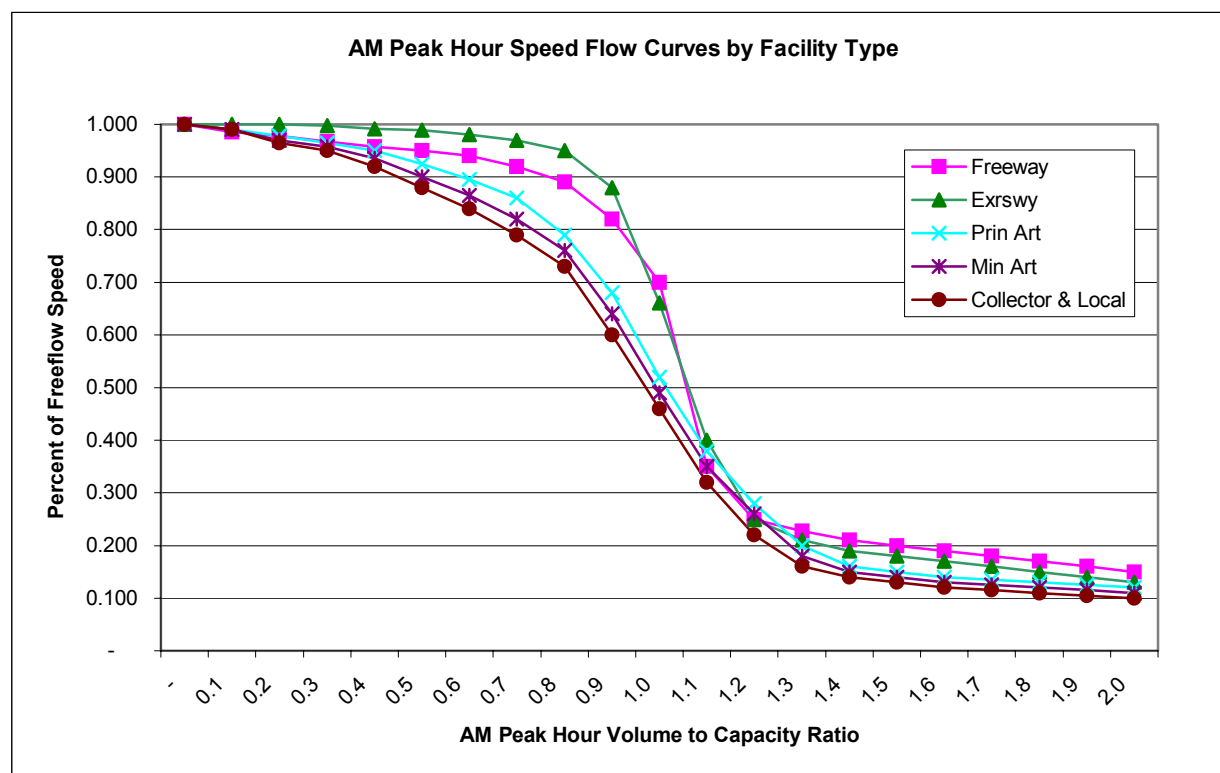


Figure 4. AM Peak Period Speed Flow Curve

Washington, DC-MD-VA (Serious Ozone Non-attainment Area) (8)

Link-Based Model and Time Period Modeled

A link-based model based on the travel model was used for emissions estimation in Metropolitan Washington area by Metropolitan Washington Council of Governments (MWCOG). The standard results of MWCOG travel demand process are 24-hour link traffic volumes and speeds. Because the emissions rates are sensitive to facility speeds over the day, which will vary with local area peaking characteristics, an effort was made to develop time-of-day specific speeds, for each link in the travel network. There are 10 discrete periods of the day used for the emissions estimation. The periods are:

- 12 midnight – 6 a.m.,
- 6 a.m. – 7 a.m.,
- 7 a.m. – 8 a.m.,
- 8 a.m. – 9 a.m.,
- 9 a.m. – 10 a.m.,
- 10 a.m. – 3 p.m.,
- 3 p.m. – 4 p.m.,
- 4 p.m. – 6 p.m.,
- 6 p.m. – 7 p.m., and
- 7 p.m. – 12 midnight.

Directional Split

A set of traffic distribution factors were developed for the 10 discrete periods of the day by the link's directional orientation toward the central downtown core of the District of Columbia. The factors were

made for inbound (heading toward the regional core), outbound (heading away from the regional core), and circumferential (heading around the CBD). Table 3 shows the distributions.

Table 3. Assumed Hourly Traffic Distributions by Link Orientation

Hourly Period	Inbound	Outbound	Circumferential
12 midnight - 6 a.m.	0.007182	0.039200	0.03600
6 a.m. – 7 a.m.	0.068402	0.022700	0.03850
7 a.m. – 8 a.m.	0.106802	0.045200	0.07200
8 a.m. – 9 a.m.	0.091902	0.047700	0.06850
9 a.m. – 10 a.m.	0.065202	0.045200	0.06800
10 a.m. – 3 p.m.	0.253402	0.250200	0.26250
3 p.m. – 4 p.m.	0.059402	0.074200	0.06500
4 p.m. – 6 p.m.	0.118402	0.200200	0.15700
6 p.m. – 7 p.m.	0.050902	0.075200	0.06250
7 p.m. – 12 midnight	0.178402	0.200200	0.17000
Total	1.000000	1.000000	1.000000

HPMS and Seasonal Adjustment

The travel model was calibrated on 1994 household survey data including check against HPMS counts. The model was then validated against 2000 HPMS count data. The model VMT of the validation year was compatible to the HPMS VMT. Therefore, no adjustment was done to the forecast years. No seasonal factors were applied to the VMT.

Post-Process Speed and Speed Model Used

An automated process was applied to estimate link operating speeds for the 10 periods of the day. The process was borrowed from a technique developed in the 1982 Air Quality Inventory work performed by MWCOG. Traffic distributions for 10 discrete periods of the day were calculated based on a regional traffic count survey conducted in 1980. The distributions were applied to the appropriate link volumes enabling the calculation of v/c ratios by time period. The ratios were then inserted into the BPR curve adapted by MWCOG to calculate daily congested speeds by time period. The results of this process were validated with observed speed data conducted in the District of Columbia and Beltway data. The MWCOG BPR curve used for the speed calculation is as follows:

$$S_r = (S_c \times 1.15) / (1 + 0.15 \times (V/C)^4); \text{ subject to } 0 \leq V/C \leq 1.6$$

Where:

Sr = restrained speed,
Sc = level of service (LOS) C speed, and
V/C = v/c ratio.

Note: If v/c exceeds 1.6, then the “excess” volume is displaced into the following time increment.

The LOS C speed and capacity used in the above equation were taken from a simple matrix based on facility type and area type. Also, the MWCOC BPR curve assumes a slower rate of speed decay for instances of extreme congestion.

VMT Mix

VMT mix fractions by vehicle type for each jurisdiction were based on an estimate of the overall non-bus HDV VMT fraction as output from MWCOC’s travel demand model combined with county-specific registration distributions and diesel sales fractions and MOBILE6 default data on the VMT mix by vehicle type within the heavy- and light-duty vehicle categories.

As determined by MWCOC’s travel demand model, the 1990 HDVs (excluding buses) account for 7.36 percent of the network VMT and 1.60 percent of local road VMT. The LDV + MC group is determined to account for 92.64 percent of the total network VMT. The local LDV + MC group accounts for 98.40 percent of the local road total VMT. The 2005 HDVs (excluding buses) account for 8.05 percent of the network VMT and 1.76 percent of local road VMT. The LDV + MC group accounts for 91.95 percent of the total network VMT.

A set of MOBILE6 input files was first prepared using each county’s registration distribution and the corresponding diesel sales fraction data for that county. These input files included no VMT mix information, and were run for a July evaluation month for a sample scenario. These MOBILE6 input files were run through MOBILE6 and the database outputs for these inputs were obtained.

The MOBILE6 database output format gives VMT fractions for each of the 28 MOBILE6 vehicle types, based on the registration distribution and diesel sales fractions supplied in the input file, as well as the MOBILE6 default VMT mix by vehicle category. Next, following the guidance included in EPA’s MOBILE6 technical guidance document (section 4.1.4), the total VMT fractions in the LDV+MC and the HDV groups in the MOBILE6 database output files were separately totaled.

Following the MOBILE6 technical guidance, the LDV and MC VMT fractions were multiplied by the ratio of MWCOC’s estimated LDV + MC VMT fraction to the default MOBILE6 LDV + MC VMT fraction. The HDV VMT fractions, excluding the bus fractions (which were multiplied by 0), were multiplied the ratio of MWCOC’s estimated HDV VMT fraction to the default MOBILE6 default non-bus HDV VMT fraction. Finally, the new VMT mixes were allocated to the 16 vehicle types required when using VMT mix as an input to MOBILE6. These VMT mixes were then used in the MOBILE6 input files.

Chicago-Gary-Lake County, IL-IN (Severe Ozone Non-attainment Area) (2)

Link-Based Model and Time Period Modeled

The Chicago Area Transportation Study (CATS) used a link-based model to calculate emissions. Multiple time period highway assignments were made to develop more accurate estimates of vehicle-miles by different speed ranges and vehicle classes for air quality conformity analyses. Separate assignments estimated highway vehicle-miles and travel speeds for eight time periods during the day:

- Off Peak (8 p.m. - 6 a.m.),
- Pre AM Peak (6 a.m. - 7 a.m.),
- AM Peak (7 a.m. - 9 a.m.),
- Post AM Peak (9 a.m. - 10 a.m.),
- Midday (10 a.m. - 2 p.m.),
- Pre PM Peak (2 p.m. - 4 p.m.),
- PM Peak (4 p.m. - 6 p.m.), and
- Post PM Peak (6 p.m. - 8 p.m.).

Directional Split

Directional volumes were output from travel model. No directional factors are applied for emissions modeling.

HPMS Adjustment

The travel model base year was 1999. The VMT has been validated for the base year to match the HPMS VMT. Therefore, no adjustment was made to the forecast years.

Post-Process Speed and Speed Model Used

A product of the time of day assignment is a traffic volume for each link by each time period of the day. The speed of travel for each link is calculated by an equation that uses the v/c ratio for the link as the independent variable. The following equations were used to produce the final link speed:

For freeways:

$$S = S_0 \frac{1}{1 + 0.15(V/C)} \frac{1}{1 + 0.15(V/C)^8} \quad \text{for } V/C \leq 1$$

$$S = S_0 \frac{1}{1 + 0.15(V/C)^8} \quad \text{for } V/C \geq 1$$

For arterials:

$$S = S_0 \frac{1}{(\ln(S_0) * 0.249) + 0.153(V/(C * 0.75))^{3.98}}$$

Where:

S = speed on link used for emission calculation,

S₀ = initial speed on link, and

V/C = v/c ratio for the link.

These curves represent modifications to the BPR curves that have been used by the CATS and other agencies for many years. Consistent with a national trend for agencies to use modified curves based on local data, these curves are based on the information gathered from local empirical data. The freeway curve is the same as used in the volume delay functions in the time of day assignment iterations. The arterial curve is slightly modified to better correlate with the empirical data. The data from the Illinois Department of Transportation's (IDOT) traffic sensor system for the expressway system and CATS

conducted speed runs for the arterial system. This data base is documented in CATS working paper 95-09, Travel Time Database and Structure Chicago Area Expressway System, September 1995, and CATS working paper 97-09, 1994, 1995, and 1996 Combined Travel Time Database Documentation: Arterial Highway System, July 1997. The methodology for the curve development is presented in CATS working paper 97-12, Method for Adjusting Modeled Speeds Based on Empirical Speed Data. August 1997.

VMT Mix

VMT were estimated by different categories. Automobile VMT in the cold start mode were estimated using the EMME/2 slave assignment option to load a cold start auto trip table to the same paths as the total automobile trip table. In addition, the time of day highway assignment process makes use of the additional options assignment procedure in EMME/2 to track four truck classes: b-plate, light, medium and heavy. These truck classes were subsequently converted into the MOBILE based truck definitions before emissions were computed.

The VMT for the assignment vehicle types were converted to the MOBILE vehicle types. The formulas used, shown below, are based upon the method developed by the Indiana EPA for the 1996 15 percent Rate of Progress (ROP) SIP.

$$\text{LDGV (warm)} = [\{\text{automobile (total)}\} - \{\text{automobile (cold)}\}] \times 0.98$$

$$\text{LDGV (cold)} = [\text{automobile (cold)}] \times 0.98$$

$$\text{LDGT1} = [\{\text{b-truck}\} \times 0.98] \times 0.70$$

$$\text{LDGT2} = [\{\text{b-truck}\} \times 0.98] \times 0.30$$

$$\text{HDGV} = [\{\text{light truck} + \text{medium truck} + \text{heavy truck}\} \times 0.98] \times 0.10$$

$$\text{LDDV} = [\text{automobile (warm)} + \text{automobile (cold)} + \text{b-truck light truck} + \text{medium truck} + \text{heavy truck}] \times 0.008$$

$$\text{LDDT} = [\text{automobile (warm)} + \text{automobile (cold)} + \text{b-truck light truck} + \text{medium truck} + \text{heavy truck}] \times 0.002$$

$$\text{HDDV} = [(\text{light truck} + \text{medium truck} + \text{heavy truck}) \times 0.98] \times 0.90$$

$$\text{MC} = [\text{automobile (warm)} + \text{auto mobile (cold)} + \text{b-truck light truck} + \text{medium truck} + \text{heavy truck}] \times 0.01$$

Philadelphia-Wilmington-Trenton, PA-NJ-DE-MD (Severe Ozone Non-attainment Area) (10)

Link-Based Model and Time Period Modeled

A link-based model based on the travel model was used for emissions estimations by the Delaware Valley Regional Planning Commission (DVRPC). The enhanced travel simulation models were disaggregated into separate peak period, midday, and evening time periods. The peak period (combined AM and PM) is defined as 7 a.m. – 9 a.m. and 3 p.m. – 6 p.m.; midday is defined as 9 a.m. – 3 p.m., and evening as 6 p.m. – 7 a.m. The traffic outputs from these time periods were aggregate into daily result. The resulting daily volumes were disaggregated to hourly volumes via a series of factors determined from traffic counts. The hourly factors by functional class and area type were developed using traffic counts. These traffic counts data were from 2000. The hourly traffic was combined with MOBILE6 emissions factors to obtain emissions.

Directional Split

Directional volumes were output from travel model. No directional factors were applied for emissions modeling.

HPMS and Seasonal Adjustment

The base year of the travel model was 1997. The VMT has validated with HPMS VMT. The model VMT was compatible with HPMS data. No HPMS adjustment was made on future year VMT. The seasonal factors were used to adjust average daily traffic volumes to summer conditions. These factors extensively relied on traffic count data. Table 4 shows the seasonal factors by county and functional class.

Table 4. Seasonal Factors by County and Functional Class

County	Summer Factors			
	Freeway	Arterial	Local	Ramp
Bucks	1.114	1.098	1.085	1.114
Chester	1.111	1.095	1.086	1.111
Delaware	1.118	1.105	1.084	1.118
Montgomery	1.116	1.098	1.084	1.116
Philadelphia	1.118	1.104	1.084	1.118
Burlington	1.111	1.099	1.086	1.111
Camden	1.118	1.100	1.084	1.118
Gloucester	1.111	1.090	1.086	1.111
Mercer	1.105	1.101	1.085	1.105

Post-Process Speed and Speed Model Used

The post-processor for air quality calculated hourly speeds for each link in the simulation highway network, given the assigned volume, functional class, and area type. Separate methodologies were used for freeways and arterials.

The speed curve equations are presented in “Impact of Preaggregation of Highway Network Travel Data on Accuracy of MOBILE4-Based Emissions” in *Transportation Research Record 1366*.

Following is the Modified Creighton, Hamburg surface arterial equations:

$$S(w_s, n) = \frac{3,600}{(\frac{3,600}{w_s}) + 12.5n}$$

$$f(n) = -0.336n^3 + 3.905n^2 - 16.116n \quad \text{if } n < 5.5$$

$$f(n) = 0.69n - 39.14 \quad \text{if } n \geq 5.5$$

For $d_s \leq 0.8c_s$

$$a = S(w_s, n) + d_s f(n)$$

For $1.4c_s > d_s > 0.8c_s$

$$m = \frac{S(w_s, n) + 0.8c_s f(n) - S_m}{-0.6}$$

$$b = 2.333S(w_s, n) + 1.867c_s f(n) - 1.333S_m$$

$$a = \frac{md_s}{c_s} + b$$

For $d_s \geq 1.4c_s$

$$a = S_m$$

Where:

a = average surface arterial speed (mph),

d_s = surface arterial volume per lane (vehicle/sec),

n = number of signals per mile,

w_s = surface arterial speed limit (mph),

c_s = surface arterial capacity per lane (vehicle/sec),

$S(w_s, n)$ = free flow speed for a given speed limit and given number of signals per mile,

$f(n)$ = rate of speed change with volume, and

S_m = minimum speed (mph).

Following is the Modified Creighton, Hamburg surface freeway equations:

$$K_2 = \ln\left(\frac{3,600}{K_1 S_c} - \frac{3,600}{K_1 w_f}\right)$$

For $c_f > d_f$

$$S = \frac{3,600}{K_1 \exp\left(\frac{K_2 d_f}{c_f}\right) + \frac{3,600}{w_f}}$$

For $c_f < d_f$

$$S = \frac{3,600}{K_1 \exp\left[K_2 \left(\frac{d_f}{c_f}\right)^{1/2}\right] + \frac{3,600}{w_f}}$$

Where:

- S = average freeway speed (mph),
- w_f = speed limit on freeways (mph),
- c_f = freeway capacity per lane (vehicle/hr),
- d_f = freeway volume per lane (vehicle/hr),
- K1 = 0.4,
- K2 = intermediate value, and
- Sc = speed at capacity.

VMT Mix

Vehicle type mix was calculated from algorithms using a combination of MOBILE6 default percentages and Pennsylvania Department of Transportation (PENNDOT) truck percentages from roadway data. The vehicle type pattern data was developed from several sources of information:

- hourly distributions for trucks and total traffic compiled by PENNDOT's Bureau of Planning and Research, according to Procedures for Adjusting Traffic Counts, 1999;
- PENNDOT truck percentages from the roadway management system (RMS) database; and
- MOBILE6 default vehicle type breakdowns for the analysis year.

The vehicle type pattern data was developed for each county and functional class combination. First, RMS truck percentages were averaged for all roadways within a county, functional class grouping. Using this percentage data, the total roadway volume for any segment could be divided to both auto and truck vehicle type categories. However, these percentages do not yet enable volumes to be divided to each of the 16 MOBILE6 vehicle types. As a result, MOBILE6 default vehicle type breakdowns were then used to divide the automobile and truck percentages to each specific MOBILE6 vehicle type. Note that the defaults used vary by analysis year; as a result, each forecast year used a unique vehicle mix distribution. PENNDOT hourly distributions for trucks and total traffic were then used to create vehicle type percentage breakdowns for each hour of the day.

Providence (All Rhode Island) (Serious Ozone Non-attainment Area) (11)*Link-Based Model and Time Period Modeled*

A link-based model was used to calculate emissions by the VHB, Inc. for the Rhode Island Department of Administration. Link VMT was split into VMT occurred during free flow conditions and that occurred during congested conditions. Thus, the emissions were modeled by peak and off-peak time periods. Currently, the Rhode Island Statewide Traffic model provides daily VMT. This daily VMT was divided into peak and off-peak VMT using congestion factors derived from the 1990 National Personal Transportation Study which documented the percent of vehicle trips made by hour by trip purpose. The congestion factors were applied to the model VMT data based on time-of-day and functional class. Using these congestion factors, a percentage of the VMT could be assigned to a reduced congested travel speed for purpose of the emissions calculations. A value of 0.7 V/C ratio was used as the cutoff between off-peak and peak VMT. These calculations were performed on a link-by-link basis.

Directional Split

No directional split factor was applied on the total link volume.

HPMS and Seasonal Adjustment

The travel demand model output data were first calibrated to the HPMS traffic data, which the Rhode Island Department of Transportation (RIDOT) collects from a sample of non-local roads throughout the state for FHWA reporting requirements. Seasonal adjustment factors (SAFs) were applied to convert AADT model output to the appropriate typical months for ozone and CO. These SAFs were calculated for each functional class for the 2000 summer and winter seasons.

Post-Process Speed and Speed Model Used

The link-by-link congested and free flow speeds were directly obtained from the travel demand model. The congested daily speed was used for the peak hour emissions calculation. The free flow speed was used for the off-peak hour calculation.

VMT Mix

The total VMT for each link was desegregated by vehicle type by applying the Rhode Island statewide VMT mix percentages. The VMT mix was developed through an iterative consultation process with Rhode Island Department of Environmental Management (RIDEM) and EPA staff using state vehicle registration data. The same VMT mix was used for all forecast years.

ANALYSIS EFFECT OF CRUCIAL FACTORS

It can be seen from Table 1 that the agencies from the five non-attainment areas use different methodologies to model on road vehicle emissions. Different methodology in modeling the same area could result in different emissions estimated. The following section explores effects of the crucial factors investigated on emission estimations individually.

Link-Based Model and Time Period Modeled

As can be seen from Equation 1, a key input to the MOBILE suite of models is the average speed per vehicle classification over the predefined section of road. MOBILE user guide does not explicitly state the length of the roadway section. This is problematic because it is easy to show that simply lengthening

the analysis section will produce less accurate emissions estimation. Similarly, by increasing the analysis period will produce less accurate emissions estimation (*12*).

The travel demand model network provides a source of spatially disaggregate VMT, and therefore emissions. Following the EPA's suggestions, agencies from all five areas performed their emission modeling based on the travel model network, which eliminate the potential inaccuracy of roadway section aggregation.

The agencies from the five areas, however, model vehicle emissions in different time periods. Different temporal allocation could result in different emission estimations. One of the major enhancements of MOBILE6 is the increased detail of traffic that can be input to the emissions model. MOBILE6 requires the emissions estimated by each of the 24 hours of the day. Most of the five areas are still in the transition phase of moving to MOBILE6. The potential inaccuracy caused different temporal aggregations will be eliminated once all the non-attainment areas use the MOBILE6 for emission estimations.

Directional Split

Directional split factors are used to allocate the VMT by direction. The aggregation and accuracy of the split factor also causes differences in emission estimations. Most areas have updated their travel demand model so that directional VMT can be produced. However, directional split factor is still a source of inaccuracy for the area that performs non-directional assignment.

HPMS and Seasonal Adjustment

The agencies from all five areas adjusted for HPMS in their emission inventory as suggested by the EPA. Whether the model VMT adjusted by the road functional class could make a difference in emission estimations. HPMS VMT is provided in categories of different road functional classes. Simply adjusting the model VMT total to the HPMS total could over or under estimate the VMT for different functional class, which in turn over or under estimate the emissions. Whether the VMT is adjusted by the seasonal fluctuation also has an effect on emissions calculated. Ozone is at the highest level during the summer time when vehicle travel is also the busiest among all seasons.

Post-Process Speed and Speed Model Used

The agencies from all five areas have used their own speed models to estimate the emissions. Different speed models may predict different speeds for the same roadway segment under same traffic conditions. Although each of the five areas used the speed model that best describes the speed situation in its area, some of the speed models are based on the speed study conducted 20 years ago (MWCOG). Updating the speed model to best simulate the field observation may eliminate the potential inaccuracy.

VMT Mix

VMT mix is another potential source of emission estimation inaccuracy. Since the emission factors from MOBILE models are generated by vehicle type. It is essential to estimate the VMT by vehicle type. EPA has not given any specific guidelines regarding how to estimate the VMT mix. As seen from the investigations conducted for the five areas, no standard practice in the five areas for producing the VMT mix. MOBILE6 improves the emission factors by increasing the number of vehicle types from 8 in MOBILE5 to 16. The improvement gives the opportunity to use the accurate emission factors for different vehicle types, however, creates difficulties to estimate the VMT mix.

CASE STUDY

A preliminary study was conducted to illustrate the effect of crucial factors on emissions calculated. The effect of temporal allocation of the VMT was not analyzed because the potential inaccuracy caused different temporal aggregations will be eliminated once all the non-attainment areas use the MOBILE6 for emission estimations (as discussed in the first bullet of the above section). The effect of VMT mix on emissions was not investigated in the case study either. A study scenario analyzed the effects of each of the other three factors individually.

Study Assumptions

A hypothetical area with 20,000,000 daily VMT was assumed. Two-hour morning peak counts for 12% of daily VMT, 40% from freeways and 40% from major arterials. The average volume to capacity (V/C) ratio for freeways was 1.0 and 0.8 for arterials for the AM peaks. It was assumed the free flow speed is 60 mph for freeway and 35 mph for the arterials. Four scenarios were calculated for this study. Assume the VMT mix is the same for both freeways and arterials. The VMT mix for the eight vehicle types in MOBILE5 is listed below:

VMT mix	0.703	0.172	0.076	0.020	0.002	0.001	0.023	0.002

The assumptions of the each scenario are described below:

- Base case scenario: non-directional total volume was used for speed and emission estimation (as was used in Rhode Island emission estimation). The VMT is HPMS adjusted, but not seasonal adjusted. The standard BPR function was used to estimate the speed on the roads. The speed equation (equation 3) is shown below:

$$S = S_f / (1 + a \cdot (V/C)^b) \quad (3)$$

Where:

S = predicted average speed,

S_f = free flow speed,

V = volume,

C = practical capacity,

a = 0.15, and

b = 4

- Scenario 1: 60-40% directional split was applied on the total volume of freeways to estimate the directional speed and emissions with everything else being the same as in the base case.
- Scenario 2: seasonal factor of 1.08 was applied for summer season which ozone level is the highest among all seasons with everything else being the same as in the base case.
- Scenario 3: ATR speed curve (shown in Figure 4) was used to estimate speeds for freeways with everything else being the same as in the base case.

Study Results

The emission rates were calculated for speeds ranging from 3 mph to 65 mph using MOBILE5 based on Houston, Texas area's air temperature, vehicle fleet age and fuel data. The setups for MOBILE5 runs and the resulting emission rates are shown in Appendix A and B respectively.

The VMTs and average speeds were calculated for both directions of the freeways and arterials for all scenarios and are shown in Table 5. Table 6 lists the emissions calculated for the four scenarios.

Table 5. VMT and Average Speed for the Hypothetical Area

	Freeways				Arterials			
	Direction1		Direction2		Direction1		Direction2	
	VMT	Average speed (mph)	VMT	Average speed (mph)	VMT	Average speed (mph)	VMT	Average speed (mph)
Base Case	480,000	52	480,000	52	480,000	30	480,000	30
Scenario 1	576,000	46	384,000	56	480,000	30	480,000	30
Scenario 2	518,400	50	518,400	50	518,400	29	518,400	29
Scenario 3	480,000	30	480,000	30	480,000	30	480,000	30

Table 6. Emissions Calculated for the Four Scenarios

	VOC (kg)	NOx (kg)
	(% difference Vs Base Case)	(% difference Vs Base Case)
Base Case	2,490	5,748
Scenario 1	2,521 (1%)	5,677 (-1%)
Scenario 2	2735 (9.8%)	6026 (4.8%)
Scenario 3	2,918 (17%)	5,299 (-7.8%)

DISCUSSIONS AND CONCLUSIONS

An integration emission model with travel demand models is the current practice to estimate mobile source emissions. The emission estimation procedure requires the travel demand model outputs post processed and adjusted before input for emission modeling. The EPA has not given detailed guidelines and standardized procedures for estimating some crucial components (i.e. VMT and speed) in emissions calculation. Differences in post process procedures and adjustment methods cause differences in emissions calculated.

Five ozone non-attainment areas were investigated for their practice of post process procedures and adjustment methods. The investigation shows that the agencies from each of the five areas uses different methodologies to post process the travel model outputs and estimate the emissions. The spatial and temporal VMT disaggregating is different for all five areas. In addition, each area used different speed models for post processing the link speeds. The MOBILE6 is a major improvement over MOBILE5 by disaggregating the emission factors. However, the increased disaggregating emission factor creates difficulties for generating the same level of details in vehicle activity data.

This investigation provides the information of different practice existed in emission estimation. The potential non-attainment areas under the new standard may use this information to start with their emission modeling. In addition, the EPA can use the information to provide a more standardized procedure for emission estimation.

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APPENDIX A: MOBILE5 SETUP FOR CASE STUDY

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5      Prompt
harris 24 hour 2007
1      Tamflg - Default Tampering Rates
4      Spdflg - One speed for all scenarios + trip length distribution
3      VMflg - User Specific VMT mix
3      Mymrflg- County Specific Reg Dist
2      Newflg - HDDV emission rates conversion factors
22     IMflg - Harris county I/M program
1      Alhflg - No additional correction factors
5      ATPflg - ATP and Pressure test
5      Rlfflg - Zero-out refueling emissions
2      Locflg - One LAP for all scenarios
1      Tempflag Mobile calculates exhaust temperature
4      Outfmt - 80 column output format
4      Prtflg - Print HC emission factors only
1      Idflg - No Idle factors calculated
3      Nmhfllg - Print HC = VOC
2      HCflg - Print Total HC
.699.171.076.018.002.001.031.002 VMT mix: LDGV,LDGT1,LDGT2,HDGV,LDDV,LDDT,HDDV,MC
.066 .088 .079 .077 .078 .076 .068 .067 .076 .068 Harris Co LDGV..MY AGES 1-10
.043 .043 .037 .029 .031 .024 .017 .010 .024 .017 LDGV..MY AGES 11-20
.004 .004 .002 .002 .012 LDGV..MY AGES 21-25
.062 .083 .080 .075 .080 .074 .059 .066 .074 .059 LDGT1.MY AGES 1-10
.038 .046 .038 .024 .030 .027 .020 .014 .027 .020 LDGT1.MY AGES 11-20
.006 .007 .004 .004 .017 LDGT1.MY AGES 21-25
.094 .099 .076 .070 .069 .059 .034 .052 .059 .034 LDGT2.MY AGES 1-10
.043 .049 .029 .029 .046 .034 .030 .023 .034 .030 LDGT2.MY AGES 11-20
.005 .003 .002 .002 .006 LDGT2.MY AGES 21-25
.061 .069 .066 .071 .066 .061 .052 .049 .061 .052 HDGV..MY AGES 1-10
.031 .058 .048 .039 .052 .042 .027 .017 .042 .027 HDGV..MY AGES 11-20
.012 .009 .007 .004 .015 HDGV..MY AGES 21-25
.066 .088 .079 .077 .078 .076 .068 .067 .076 .068 LDDV..MY AGES 1-10
.043 .043 .037 .029 .031 .024 .017 .010 .024 .017 LDDV..MY AGES 11-20
.004 .004 .002 .002 .012 LDDV..MY AGES 21-25
.062 .083 .080 .075 .080 .074 .059 .066 .074 .059 LDDT..MY AGES 1-10
.038 .046 .038 .024 .030 .027 .020 .014 .027 .020 LDDT..MY AGES 11-20
.006 .007 .004 .004 .017 LDDT..MY AGES 21-25
.048 .042 .071 .074 .064 .059 .053 .062 .059 .053 HDDV..MY AGES 1-10
.036 .056 .067 .050 .053 .034 .024 .011 .034 .024 HDDV..MY AGES 11-20
.008 .005 .002 .002 .006 HDDV..MY AGES 21-25
.056 .061 .043 .047 .057 .048 .052 .079 .048 .052 MC....MY AGES 1-10
.061 .377 .000 .000 .000 .000 .000 .000 .000 .000 MC....MY AGES 11-20
.000 .000 .000 .000 .000 MC....MY AGES 21-25
004
1 7 3 90 90 05.639 00.000
1 7 3 91 97 04.598 00.000
1 7 3 98 03 03.679 00.000
1 7 3 04 20 01.840 00.000
96 20 83 05 03 03 096 1 1 2222 4211 0.80 15.0 2.00 I/M Prog2/ASM/IMdata4.d
84 83 05 2222 11 096 22112222 ATP
96 83 05 2222 11 096 Pressure Test
Harris B 67 92 7.8 7.8 92 2
13.7 26.9 22.6 15.1 09.1 12.6
4 07 xxxx 84.0 15.1 14.3 23.7 7
01 2

```

APPENDIX B: EMISSION RATES FOR CASE STUDY

speed		LDGV	LDGT1	LDGT2	HDGV	LDDV	LDDT	HDDV	MC
3	VOC	3.679658	4.286111	6.391	7.122347	1.024427	1.429794	4.445225	14.09523
4	VOC	2.681379	3.130512	4.707	6.004912	0.9725961	1.357454	4.220319	12.25282
5	VOC	2.140827	2.499444	3.776	5.294258	0.9242003	1.289908	4.010319	10.88825
6	VOC	1.8048	2.10469	3.188	4.767779	0.878986	1.226802	3.814123	9.858269
7	VOC	1.576704	1.835437	2.784	4.345599	0.8367195	1.167811	3.630719	9.0674
8	VOC	1.435096	1.665795	2.521	4.02416	0.7971867	1.112635	3.459177	8.45058
9	VOC	1.326674	1.535358	2.318	3.742163	0.7601904	1.060999	3.298641	7.962584
10	VOC	1.239184	1.429816	2.154	3.489802	0.7255492	1.01265	3.148325	7.571369
11	VOC	1.166918	1.342378	2.019	3.26304	0.6930963	0.9673556	3.007505	7.253834
12	VOC	1.106069	1.26852	1.906	3.058619	0.6626777	0.9249004	2.875512	6.993045
13	VOC	1.054005	1.205107	1.809	2.873834	0.6341521	0.8850871	2.751732	6.776395
14	VOC	1.00884	1.149901	1.725	2.706401	0.6073887	0.8477333	2.6356	6.594372
15	VOC	0.9691963	1.101261	1.651	2.554364	0.5822669	0.8126707	2.52659	6.439698
16	VOC	0.9340381	1.057956	1.585	2.416041	0.5586756	0.7797444	2.424222	6.306751
17	VOC	0.902574	1.019044	1.527	2.289961	0.536512	0.7488106	2.328049	6.191143
18	VOC	0.8741883	0.9837927	1.474	2.174844	0.5156813	0.7197372	2.23766	6.08942
19	VOC	0.8483947	0.9516248	1.426	2.069561	0.4960957	0.6924015	2.152674	5.998854
20	VOC	0.8173171	0.917091	1.373	1.97439	0.4776742	0.6666906	2.072738	5.917283
21	VOC	0.7860613	0.8848156	1.321	1.889083	0.4603416	0.6424995	1.997529	5.842994
22	VOC	0.7575599	0.8553836	1.275	1.810964	0.4440285	0.6197313	1.926742	5.774631
23	VOC	0.7314533	0.8284236	1.232	1.73934	0.4286706	0.5982962	1.860101	5.711133
24	VOC	0.7074423	0.8036269	1.193	1.673597	0.4142082	0.5781112	1.797345	5.651675
25	VOC	0.6852752	0.7807337	1.156	1.613186	0.4005862	0.5590988	1.738236	5.595626
26	VOC	0.6647397	0.7595244	1.123	1.557617	0.3877532	0.5411876	1.682551	5.542515
27	VOC	0.6456541	0.7398123	1.092	1.506452	0.3756616	0.5243115	1.630083	5.492004
28	VOC	0.6278631	0.7214366	1.063	1.459297	0.3642677	0.5084089	1.580641	5.443854
29	VOC	0.611233	0.704259	1.036	1.415801	0.3535303	0.4934226	1.534049	5.397916
30	VOC	0.5956476	0.6881597	1.01	1.375648	0.3434113	0.4792997	1.49014	5.354101
31	VOC	0.5810057	0.6730347	0.987	1.338553	0.3338757	0.4659908	1.448764	5.312379
32	VOC	0.567219	0.6587924	0.964	1.304262	0.3248907	0.4534505	1.409775	5.272744
33	VOC	0.5542097	0.6453525	0.943	1.272542	0.3164259	0.441636	1.373045	5.235225
34	VOC	0.5419092	0.6326443	0.923	1.243189	0.3084528	0.430508	1.338448	5.199861
35	VOC	0.5302567	0.6206049	0.904	1.216012	0.3009454	0.4200299	1.305872	5.166698
36	VOC	0.5191982	0.6091789	0.887	1.190844	0.2938793	0.4101677	1.27521	5.135784
37	VOC	0.5086856	0.5983164	0.87	1.167533	0.2872316	0.4008896	1.246365	5.107153
38	VOC	0.4986758	0.5879728	0.854	1.14594	0.2809815	0.3921663	1.219244	5.080842
39	VOC	0.48913	0.5781084	0.838	1.125941	0.2751094	0.3839706	1.193764	5.056858
40	VOC	0.4800135	0.5686872	0.824	1.107423	0.2695972	0.3762773	1.169844	5.035194
41	VOC	0.4712951	0.5596765	0.81	1.090286	0.264428	0.3690625	1.147414	5.015819
42	VOC	0.462946	0.5510474	0.796	1.074436	0.2595863	0.3623049	1.126404	4.998673
43	VOC	0.4549406	0.5427729	0.783	1.059792	0.2550574	0.3559842	1.106753	4.983672
44	VOC	0.4472555	0.5348291	0.771	1.046278	0.2508284	0.3500815	1.088402	4.970681
45	VOC	0.4398693	0.5271938	0.759	1.033827	0.2468865	0.3445799	1.071298	4.959537
46	VOC	0.4327625	0.519847	0.748	1.02238	0.2432206	0.3394633	1.055391	4.950024
47	VOC	0.4259172	0.5127702	0.737	1.011881	0.2398201	0.3347173	1.040635	4.941871
48	VOC	0.419348	0.505978	0.727	1.002298	0.2366753	0.330328	1.026989	4.934757
49	VOC	0.4181981	0.504759	0.725	0.9937513	0.2337773	0.3262833	1.014413	4.934757

50	VOC	0.4171144	0.5036102	0.724	0.9860896	0.2311181	0.3225719	1.002875	4.934757
51	VOC	0.4160917	0.5025263	0.722	0.9792738	0.2286903	0.3191835	0.9923402	4.934757
52	VOC	0.4151254	0.5015024	0.721	0.9732695	0.2264873	0.3161087	0.9827807	4.934757
53	VOC	0.4142115	0.500534	0.72	0.9680468	0.2245029	0.3133391	0.9741702	4.934757
54	VOC	0.4133462	0.4996172	0.719	0.9635807	0.2227319	0.3108673	0.9664853	4.934757
55	VOC	0.412526	0.4987483	0.718	0.95985	0.2211694	0.3086865	0.9597052	4.934757
56	VOC	0.4219997	0.5086887	0.734	0.9568372	0.2198112	0.3067908	0.9538114	5.027837
57	VOC	0.4315124	0.5186705	0.75	0.9545285	0.2186536	0.3051752	0.9487886	5.120919
58	VOC	0.4410617	0.5286911	0.766	0.9529139	0.2176937	0.3038354	0.944623	5.214
59	VOC	0.4506451	0.5387479	0.782	0.9519872	0.2169287	0.3027678	0.941304	5.30708
60	VOC	0.4602604	0.5488386	0.798	0.9517451	0.2163568	0.3019695	0.9388222	5.400161
61	VOC	0.4699055	0.5589609	0.814	0.952188	0.2159764	0.3014385	0.9371713	5.493242
62	VOC	0.4795786	0.5691128	0.83	0.9533198	0.2157864	0.3011734	0.9363468	5.586323
63	VOC	0.489278	0.5792927	0.847	0.9551479	0.2157864	0.3011734	0.9363468	5.679403
64	VOC	0.499002	0.5894987	0.863	0.957683	0.2159764	0.3014385	0.9371713	5.772484
65	VOC	0.5087492	0.5997294	0.879	0.9609399	0.2163568	0.3019695	0.9388222	5.865565
		LDGV	LDGT1	LDGT2	HDGV	LDDV	LDDT	HDDV	MC
3	NOX	1.328807	1.538004	2.452	3.250378	1.830177	2.042473	12.34274	0.8236675
4	NOX	1.214568	1.405781	2.241	3.284014	1.753095	1.95645	11.82289	0.7878255
5	NOX	1.146025	1.326447	2.115	3.317649	1.681645	1.876712	11.34104	0.7580824
6	NOX	1.100329	1.273557	2.03	3.351284	1.615401	1.802783	10.89428	0.7339704
7	NOX	1.06769	1.235779	1.97	3.384919	1.55397	1.734226	10.47999	0.7150389
8	NOX	1.043211	1.207446	1.925	3.418554	1.496999	1.670648	10.09578	0.7008528
9	NOX	1.024171	1.185408	1.89	3.45219	1.444167	1.611687	9.739482	0.6909938
10	NOX	1.008939	1.167779	1.862	3.485825	1.39518	1.557017	9.409106	0.6850601
11	NOX	0.9964767	1.153355	1.839	3.51946	1.349768	1.506338	9.102853	0.6826663
12	NOX	0.9860912	1.141335	1.82	3.553095	1.307691	1.459379	8.819084	0.6834434
13	NOX	0.9773036	1.131163	1.803	3.58673	1.268726	1.415894	8.556301	0.6870387
14	NOX	0.9697716	1.122445	1.79	3.620365	1.232671	1.375657	8.313145	0.6931158
15	NOX	0.9632434	1.11489	1.777	3.654001	1.199342	1.338462	8.088375	0.7013551
16	NOX	0.9575316	1.108279	1.767	3.687636	1.168573	1.304124	7.880867	0.7114532
17	NOX	0.9524919	1.102445	1.758	3.72127	1.140211	1.272472	7.689593	0.7231231
18	NOX	0.9480117	1.097259	1.749	3.754906	1.114118	1.243353	7.513625	0.7360941
19	NOX	0.9440033	1.09262	1.742	3.78854	1.090169	1.216626	7.352113	0.7501121
20	NOX	0.9460069	1.086073	1.732	3.822176	1.068251	1.192166	7.204299	0.7649394
21	NOX	0.9520464	1.087819	1.734	3.855811	1.048261	1.169857	7.069487	0.7803546
22	NOX	0.9575369	1.089407	1.736	3.889446	1.030108	1.149597	6.947055	0.7961527
23	NOX	0.96255	1.090856	1.738	3.923081	1.013706	1.131294	6.836445	0.8121455
24	NOX	0.9671453	1.092185	1.74	3.956716	0.9989834	1.114863	6.737156	0.8281604
25	NOX	0.9713728	1.093408	1.741	3.990351	0.9858735	1.100232	6.648744	0.8440422
26	NOX	0.9752754	1.094536	1.743	4.023987	0.9743183	1.087337	6.570816	0.8596511
27	NOX	0.9788888	1.095581	1.744	4.057622	0.9642669	1.076119	6.503028	0.874865
28	NOX	0.9822443	1.096551	1.746	4.091257	0.9556752	1.066532	6.445086	0.8895765
29	NOX	0.9853682	1.097454	1.747	4.124892	0.948506	1.05853	6.396736	0.9036962
30	NOX	0.9882837	1.098297	1.748	4.158527	0.9427282	1.052083	6.357772	0.9171504
31	NOX	0.9910112	1.099086	1.749	4.192162	0.9383173	1.04716	6.328023	0.9298816
32	NOX	0.9935683	1.099825	1.75	4.225798	0.9352539	1.043741	6.307364	0.9418493
33	NOX	0.9959705	1.10052	1.751	4.259433	0.9335252	1.041812	6.295707	0.9530287
34	NOX	0.9982312	1.101173	1.752	4.293068	0.933124	1.041364	6.293001	0.9634126

35	NOX	1.000363	1.10179	1.753	4.326703	0.9340482	1.042396	6.299234	0.9730088
36	NOX	1.002376	1.102372	1.753	4.360338	0.9363021	1.044911	6.314432	0.981842
37	NOX	1.00428	1.102923	1.754	4.393974	0.9398949	1.04892	6.338663	0.9899535
38	NOX	1.006084	1.103445	1.755	4.427609	0.9448423	1.054442	6.372029	0.9974015
39	NOX	1.007796	1.103939	1.756	4.461244	0.9511655	1.061499	6.414672	1.00426
40	NOX	1.009422	1.10441	1.756	4.494879	0.9588916	1.07012	6.466777	1.010619
41	NOX	1.010969	1.104856	1.757	4.528514	0.9680541	1.080346	6.528571	1.016585
42	NOX	1.012442	1.105283	1.757	4.562149	0.9786931	1.092219	6.600318	1.022283
43	NOX	1.013846	1.105688	1.758	4.595785	0.9908549	1.105792	6.682338	1.027852
44	NOX	1.015187	1.106077	1.758	4.629419	1.004593	1.121123	6.77499	1.033447
45	NOX	1.016468	1.106447	1.759	4.663055	1.01997	1.138284	6.878687	1.039241
46	NOX	1.017694	1.106801	1.759	4.69669	1.037053	1.157349	6.993897	1.045424
47	NOX	1.018867	1.10714	1.76	4.730325	1.05592	1.178405	7.12114	1.0522
48	NOX	1.019991	1.107465	1.76	4.76396	1.076659	1.201549	7.261003	1.059793
49	NOX	1.050376	1.149244	1.827	4.797596	1.099365	1.226889	7.414132	1.092771
50	NOX	1.08076	1.191022	1.893	4.83123	1.124145	1.254543	7.581249	1.12575
51	NOX	1.111145	1.232801	1.959	4.864866	1.151117	1.284643	7.763147	1.158729
52	NOX	1.141529	1.274579	2.025	4.8985	1.180411	1.317336	7.960709	1.191707
53	NOX	1.171914	1.316358	2.092	4.932136	1.212171	1.35278	8.174896	1.224686
54	NOX	1.202298	1.358136	2.158	4.965772	1.246554	1.391151	8.406776	1.257665
55	NOX	1.232683	1.399915	2.224	4.999407	1.283733	1.432644	8.657517	1.290643
56	NOX	1.263067	1.441694	2.291	5.033041	1.323901	1.477471	8.928407	1.323622
57	NOX	1.293451	1.483471	2.357	5.066677	1.367265	1.525865	9.220855	1.356601
58	NOX	1.323836	1.52525	2.423	5.100311	1.414057	1.578084	9.536418	1.389579
59	NOX	1.35422	1.567028	2.489	5.133947	1.464528	1.634409	9.876794	1.422558
60	NOX	1.384604	1.608807	2.556	5.167582	1.518955	1.69515	10.24385	1.455537
61	NOX	1.414989	1.650585	2.622	5.201218	1.577645	1.760648	10.63966	1.488516
62	NOX	1.445373	1.692364	2.688	5.234853	1.640929	1.831273	11.06645	1.521494
63	NOX	1.475758	1.734142	2.754	5.268487	1.709178	1.907439	11.52672	1.554473
64	NOX	1.506142	1.775921	2.821	5.302122	1.782796	1.989595	12.0232	1.587452
65	NOX	1.536527	1.8177	2.887	5.335758	1.862226	2.07824	12.55888	1.62043

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GUIDE TO UPDATE TXDOT'S ROADWAY CONDITIONS INFORMATION SYSTEM FOR ADVERSE WEATHER CONDITIONS

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SUMMARY

Weather impacts transportation safety, mobility, and the ability for motorists to travel on certain routes. Approximately 7,000 people lose their lives and 450,000 people incur injuries in crashes during adverse weather each year. When adverse weather conditions occur in a region, transportation agencies need an effective means to determine the condition of the roadways, and then disseminate this information to the traveling public, all in a timely manner.

In Texas, the Texas Department of Transportation (TxDOT) is responsible for determining roadway conditions during adverse weather conditions and providing this information to the traveling public. TxDOT's current road weather condition information system relies on maintenance personnel to collect road conditions information first-hand. This information is input into the state's Highway Condition Report on the mainframe computer. Then the information is disseminated to the traveling public via the toll-free traveler information number and the internet. Due to inefficiencies in the current system, the roadway conditions information available to the public is often not accurate because the information could be several hours old.

A survey of state transportation agencies was conducted to determine how these agencies collect road weather conditions information and what methods are used to disseminate this information to the traveling public. Of the states surveyed, a majority still relies on personnel to collect roadway conditions on-site, but states are beginning to automate their systems using Road Weather Information Systems (RWIS) and other technologies. The main methods used to provide roadway conditions information during adverse weather conditions to the traveling public are 511 Traveler Information Line or other toll-free information line, web sites, and commercial radio.

As results of the survey, and a literature review, three recommendations were made that could improve the accuracy and effectiveness of TxDOT's roadway conditions information system during adverse weather conditions. These recommendations are:

- Update the field reporting system,
- Improve procedure for information input into mainframe, and
- Improve toll-free number and web site.

These improvements would help TxDOT's roadway conditions information system to be more efficient and more effective in providing information to the traveling public during times of adverse weather.

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INTRODUCTION

Weather has a considerable impact on transportation safety, mobility, and the ability of motorists to travel on certain routes. Drivers are often faced with many unexpected situations when adverse weather conditions occur. Adverse weather conditions create potentially unsafe conditions on the roadway and often cause travelers to be delayed or travel to be postponed due to road closures. It has been estimated that 25-35 percent of all interurban traffic accidents occur during adverse weather conditions (1). More importantly, approximately 7,000 people lose their lives and 450,000 people incur injuries in crashes during adverse weather each year (2).

Travel and roadway maintenance during adverse weather also has lasting impacts on the environment. Increased travel times lead to the degradation of transportation air quality. Ozone attainment requirements critically depend on weather conditions, since attainment depends on only the four highest concentrations each year. Also 15 million tons of road salt is applied each year to protect against ice on the roadway (3).

Transportation agencies, with the advent of modern technologies, have the ability to determine the roadway condition and disseminate this information to the public in a timely manner. There are several technologies, such as road weather information systems (RWIS), which record on-site pavement and air temperatures, detect precipitation, measure wind speed, along with additional information. All of this information can be sent to a centralized location in real-time. The major methods to communicate this roadway conditions information from the field to a central office are phone, radio, microwave, and satellite (4).

The United States has a variety of climates each with varying degrees of inclement weather conditions. The same is true for the state of Texas. The northern portion of the state experiences occasional snow and ice and the southern portion of the state intermittently experiences heavy rainfall that can flood low lying areas. Although these weather conditions are dissimilar, each produces similar unsafe conditions on the roadway. The Texas Department of Transportation (TxDOT) has a system to collect roadway conditions information during adverse weather conditions and then distribute the information to the traveling public. The road conditions information that is made available by this system is often several hours old. Since adverse weather can change roadway conditions so quickly, this old roadway conditions information is often inaccurate and only adds to the unexpected situations experienced by drivers.

PROBLEM STATEMENT

Adverse weather can quickly degrade the conditions of the roadway. When adverse weather conditions occur in a region, the proper transportation agency needs an effective means to determine the roadway condition. The road conditions information that is collected needs to be disseminated to motorists in a timely manner with a method of communication that is easily accessible. The current system in place within the state of Texas is operated by the Texas Department of Transportation. Because of the current data collection and reporting procedures, this system provides roadway conditions information to the traveling public that is often several hours old. This old information many times is no longer accurate due to the rapidly changing conditions. The roadway conditions information system needs to be updated so that there is less delay in making road conditions information available to the public.

OBJECTIVES

A set of recommendations was generated during this study that would improve TxDOT's roadway conditions information system during adverse weather. Four objectives were established in order to reach the set of recommendations. These research objectives were:

- Determine the current road weather conditions information system used by TxDOT,
- Determine the road weather conditions information systems used in other states,
- Identify the benefits and drawbacks to road weather conditions systems used in other states, and
- Recommend upgrades that could be implemented to TxDOT's current road weather information system.

SCOPE

Recommendations are made for updates to the statewide road weather information system in Texas. Applications of technology, such as intelligent transportation systems (ITS) technologies, that relay road weather conditions information to a centralized location are explored and recommended according to how the motorist is benefited. The benefits to roadway maintenance operations that these applications of technology could potentially offer are not discussed within this study. These recommendations are expected to be most useful at a statewide level. That is, the recommended system upgrades are not directed toward local traffic management centers, or any similar regional transportation agency centers.

BACKGROUND

There have been numerous studies conducted that focus on ITS technologies that record roadway conditions information. The technologies reviewed are: Road Weather Information Systems (RWIS), fog detection and warning systems, and high-water detection and warning systems. Also, the data collected by these technologies requires a means of communication to get the information to a control center so it may be disseminated to the public. Methods to communicate this information are reviewed below.

Road Weather Information Systems (RWIS)

RWIS's sense and collect on-site weather and road conditions information in real-time, process, and disseminate this information, and have the ability to create forecasts of road and weather conditions (5). A RWIS consists of several components. These include:

- Sensors,
- Remote processing units (RPUs),
- Central processing units (CPUs), and
- Telecommunications equipment that transmits the data.

Sensors

Systems can be fit with a varying complement of sensors, ranging from simple system that only uses one sensor to a fully-loaded system that utilizes many sensors. The types of sensors available include: surface (pavement) sensors, subsurface temperature sensors, and atmospheric sensors (1). RWIS can also be equipped to provide video images of roadway conditions (6).

Pavement temperatures are recorded by electronic devices installed in the roadway. Roadway sensors are installed flush with the pavement surface and color matched with the pavement so that both respond to incident light energy at the same rate. The sensor's output signal is designed to reflect the condition on top of the sensor, which approximates conditions of the surrounding roadway pavement surface;

- Dry,
- Wet (above 0 degrees C),
- Wet (not frozen but at or below 0 degrees C),
- Snow/ice alert (at or below 0 degrees C),

- Dew,
- Frost, and
- Absorption.

Subsurface temperatures are recorded by probes that are installed directly below the surface sensor at a depth of approximately 16 inches. These provide heat flux information for computer models that predict pavement temperatures.

Atmospheric sensors include sensors that record air temperature, relative humidity, wind speed and direction, and precipitation. Air temperature is typically measured over a range of -80 to 160 degrees F, and relative humidity is measured over a range of 10-100 percent. Precipitation is detected by sensing interruption in an infra red optical beam.

Remote Processing Units (RPU)

Remote processing units (RPUs) are located at the site of a RWIS and process the raw data that are collected by the sensors. The data from the sensors, in analog or digital format, are converted by the RPU to a usable form. This data are then transmitted directly to a roadside message sign, other type of sign, or to a CPU. A RPU is usually powered by battery or solar power (4).

Central Processing Unit (CPU)

The CPUs are typically located at a control office. The CPUs analyze, store, and organize the data from the RPUs and convert the data into information and graphical displays to be used by decision makers or meteorologists.

Telecommunications Equipment

RWIS information can be transmitted by several communication methods such as direct wired connections, telephone, cellular links, radio, microwave, satellite, and others. A direct wired connection only requires the necessary cable to connect the system. Telephone communication requires telephone lines and modems. Transmitters, receivers, antennas, and sometimes repeaters are needed for radio communication. Microwave and satellite communication are slightly more expensive unless this equipment is already in place for other reasons (4,7). Methods of communication are described in more detail in below sections.

Costs and Benefits of RWIS

The cost of a RWIS consists of capital costs and annual operations and maintenance costs. Capital costs include the purchase and installation of the RWIS equipment, including hardware and software. These costs vary depending on the complexity of the system. Typical RWIS have capital costs in the range of \$10,000 to \$40,000 per site, with an additional \$25,000 for the necessary communications equipment and a CPU equipped with applicable RWIS software (8). Also, RPUs and CPUs will need to be replaced approximately every five years in order to stay current with technological advances. These costs should be included with capital costs but need to be adjusted using a discount factor when calculating the net present value of the RWIS system.

The annual costs associated with the operation of a RWIS could include long distance telephone charges, costs of meteorological services, or other charges. These operations costs can vary depending on what type of communication is used, and how often the information is communicated from the RPU to the CPU. This communication may only take place several times each day during normal operation, but during periods of adverse weather this communication can be as frequent as once per minute or more.

Maintenance of RWIS systems includes things such as sensor calibration, equipment repair, and replacement of damaged equipment. Maintenance costs can be estimated by using past experiences of other highway agencies. For example, in 1993 the Colorado Department of Transportation (CDOT) reported their average annual maintenance costs to be \$6,200 for eight RWIS roadside installations (9). Other states are purchasing some type of maintenance contract from the RWIS vendors. In these contracts, the vendor receives an annual flat fee for repairing, replacing, or calibrating RWIS components when necessary. The cost of these contracts usually ranges from approximately \$1,900 to \$4,100 per RPU site per year (8).

A RWIS also provides many benefits, quantified as direct savings, indirect savings, and social cost savings. Direct savings include decreasing winter maintenance costs due to decreased patrols, savings in labor and equipment use, and decreased use of materials. Indirect savings result from the reduced risk of liability. Social costs incurred by the public and the environment, such as travel costs, pollution costs, and accident costs can also be reduced by the installation of RWIS.

The need for routine patrolling should be all but eliminated in areas where RWIS equipment has been installed and calibrated. Usually, an agencies maintenance department is responsible for these patrolling duties. So a reduction in patrolling time also means that more maintenance personnel will be available for other tasks. The other types of direct savings are outside the scope of this project.

Indirect savings come from the reduced risk of liability. Since a RWIS should give drivers more accurate information about driving conditions, the risk of lawsuits resulting from hazardous road conditions should decrease. Unfortunately, this type of savings is difficult to quantify because there is no evidence that lawsuits are directly correlated with traffic accidents (8).

Social costs savings include travel costs, pollution costs, and accident costs. Travel cost savings include time saved, or even avoidance of injury or death, because the traveler was informed of current roadway conditions and could decide their travel plans accordingly. Earlier research conducted in Wisconsin and Finland has found that savings from travel and pollution costs are negligible, when compared to other RWIS costs and savings (10,11). Accident rates can have a significant amount of variance depending on geographic region where a RWIS is to be implemented. The benefit of social cost savings should be evaluated as a region specific savings.

Fog Detection Systems

Fog accidents are rare events compared to other accident types, but when fog accidents do occur they tend to be multi-vehicle accidents that result in major highways being shut down and include a high number of fatalities. Only a hand-full of fog detection systems have been implemented in the United States, but the agencies that have reported the results of such systems have shown considerable safety improvements (6).

A fog warning system typically includes one or more visibility sensors, an on-site controller, and a means to communicate information to motorists, such as a variable message sign (VMS). The Federal Highway Administration has conducted at least one study on highway fog warning systems. In this study a sensor known as a nephelometer was used as the method of detection. Basically, a nephelometer consists of a light emitter and a light detector. The sensor unit is designed to provide accurate fog density measurement, low maintenance requirements, and a selectable output format (visibility in distance units or voltage proportional to fog density) (12). It also is able to detect blowing snow that causes "white out" conditions during adverse winter weather.

The data obtained by the nephelometer are digitized and transferred to a host computer. There are five optional communication links available between the sensors and the host computer for this system: cable, fiber optics, telephone, cellular, and radio frequency. The host computer can be as simple as a personal computer or a laptop computer, and this computer can be located near the sensors or remotely.

The costs associated with implementing a fog detection system are not as significant as they were in past years. The first fog warning systems included visibility sensors that had a price range of \$10,000-\$12,000 each. New fog detection sensors are available in the price range of \$4,000-\$5,000 each. These newer, lower priced, sensors have accuracy and sensing types better suited for the roadway environment. A small fog detection system will typically begin around the price range of \$85,000-\$90,000 (6).

Several states have implemented fog warning systems on fog-prone sections of roadway. South Carolina installed a fog warning system to monitor the visibility of a section of Interstate 526 which crosses the Cooper River. There are five fog detectors and one weather station that make up this fog warning system. When the fog sensors indicate that visibility has been reduced, a maintenance dispatcher observes the conditions from a roadway camera to verify the conditions. Then the dispatcher activates an appropriate message on the variable message signs (VMS) and also activates the roadway lights. These roadway lights are airport lights which have been embedded in the roadway to aid drivers during periods of reduced visibility (1).

Tennessee installed a fog warning system on a 19 mile stretch of Interstate 75 that crosses the Hiwassee River. Eight fog detectors and two weather stations monitor conditions in this fog-prone area. When conditions reach fog generating levels, safety personnel can activate any of 10 VMS along with flashing lights on fixed message signs. Variable speed limit signs are used to reduce the speed, if necessary. During the first two years of system operation (1993-1995), no fog-related incidents were reported (1).

High-Water Detection Systems

High-water detection systems are usually a separated entity from a RWIS because most RWIS's do not include water-level sensors. High-water detection systems are usually a part of a flood warning system that is associated with a region's or city's storm water management department. The authors Weissmann, et. al. (4) described two such systems found in Texas: RTC – High-Water Detection and Warning Systems, and Remote Operating System – Low-Water Crossing System.

RTC – High-Water Detection and Warning System

This type of system is installed in low-lying areas where high-water is a potential hazard. This system consists of water-level sensors, an RPU, a power source, a radio transmitter with antenna, and message signs. The message signs usually consist of a flashing yellow light, a flashing red light, and a changeable sign to show when the road is closed. The sensor information is communicated via VHF radio to both the warning signs and to the control center. A submerged optical sensor sends a signal to activate the flashing yellow light when water reaches a predetermined level. Another sensor indicates when the water level rises above the road. This sensor activates the flashing red light and actuates the changeable sign to warn that the road is closed. The cost of this type of system, using solar power, is approximately \$18,000.

Remote Operating System – Low-Water Crossing System

The Remote Operating System basic low-water crossing system consists of continuous water level sensors, a solar powered RPU, radio and antenna, an enclosure for the RPU, and some type of message signs. The digital level sensor is installed off to the side of the roadway and sends data to the RPU. The RPU activates an alarm and lights on the message signs when the water level reaches a predetermined level (usually 6 inches to 12 inches). The alarm and water level data are also transmitted to a CPU in the control center. This type of system costs approximately \$5,000, but this price does not include the cost of the message signs or installation. The message signs are usually provided by a different vendor.

Methods of Communication

Communication is needed to get the road conditions information from the on-site location to the public as quickly and efficiently as possible. If ITS technologies are located on-site, then typically the communication begins with transferring the collected data from the sensors to the RPU. The RPU transmits the data to the CPU or directly to the public. The information that is sent to the CPU also is transmitted to the public. Typical methods of communicating this information will be reviewed.

Sensors to Remote Processing Units

In most applications, the sensors are hardwired to the RPU. The data from the sensors is transmitted either by an analog or digital signal over the wires.

Remote Processing Unit to Central Processing Unit

The main forms of communication used to transmit information from the RPU to the CPU include phone, radio, microwave, and satellite (4).

When information is transferred by phone, the RPU sends it via modem to the CPU either automatically or when the information is requested by the CPU. This information can also be sent by cellular phones if it is too costly to install or maintain a phone line. Costly long-distance charges create another reason to use the cellular phone option to communicate. The cost of phone communication is one problem associated with this method. Phone lines have monthly costs, possible long-distance charges, or air-time charges if cellular phones are used. Another problem with this method is phone occasionally become inoperable during storms, which is when the data are needed the most.

A UHF/VHF line-of-site radio is another widely used method of communicating between an RPU and CPU. Communicating by this method requires the RPU to have a radio transmitter and the CPU requires a receiver. Also, an FCC license is required to transmit signals on a certain frequency. A drawback to this method of communication is that it requires the devices to have a line-of-site. If a line-of-site is not possible, then a repeater tower or some other device would be needed to get the signal from the RPU to the CPU. The cost of a radio system is typically in the range of \$500 to \$1,000. This method has an advantage over the phone method in that there are no monthly charges associated with the service. A disadvantage to radio communication is that a line-of-site needs to be established. This is a foreseen major problem for the state of Texas where it is anticipated that signals will need to be sent over relatively long distances.

For long distance communication, the microwave technology is a reliable method. The most common ways of using microwave for communication includes transmitting by line-of-site radio to the microwave tower, and then convert the signal to microwaves. This would require a radio receiver/microwave converter to be installed on the microwave tower. Due to the considerable expense of the microwave technologies, this method would be feasible only if the microwave towers were already in place. There is an existing microwave network in Texas that is owned by Valero, a natural gas supplier and distributor (4). It is possible a microwave line could be leased from Valero for a monthly fee. Ideally this fee would also include maintenance costs.

Another method of communication between the RPU and a CPU is satellite. A satellite communication system consists of a satellite transmitter and a telemetry antenna at the RPU to send the data and a satellite receiving unit and antenna at the CPU for receiving the data. Although this method of communication has been considered too costly in the past, its price is now dropping to a level that would be feasible for some applications.

Remote Processing Unit to the Public

An RPU sends information to the traveling public to warn of possible hazardous conditions by activating flashing lights, variable message signs, or a combination of both. Typically, once the RPU receives data from a sensor that indicates an alarm, the RPU sends the signal to the flashing lights and/or variable message signs thru a hardwired link or by radio. The RPU sends a signal to deactivate the warning devices once the hazard is over.

Central Processing Unit to the Public

There are numerous ways to send road weather conditions information to the traveling public. Several methods currently used include, television broadcasts, radio advisories, traveler information telephone numbers, transportation agencies web sites, and kiosks at public rest stops.

Weather information broadcast by television is often retransmitted forecasts that are issued by the National Weather Service (NWS). According to some maintenance engineers interviewed in an earlier study (4), public forecasts are often too conservative to provide sufficient details that can be related to specific sites. Radio advisories typically reiterate NWS forecasts, and can relay road conditions information provided by a local transportation agency during adverse weather conditions. Besides public radio broadcasts, travelers could also access highway advisory radio (HAR). HAR is a service provided in local areas that has a maximum range of approximately ten miles, but a clear listening range of three to five miles depending upon the conditions. Where HAR is available, roadside signs are often posted informing motorists of the radio frequency that the HAR utilizes. A downside to these information sources is they are usually only available to travelers in the local vicinity of the broadcasts. These methods of communicating road weather conditions would not be available to truckers and other long-distance travelers outside of the local area.

Traveler information telephone numbers are usually operated by state or local transportation agencies, and even public transit agencies. There are over 300 of these numbers across the country (13). These numbers provide a wide array of traveler information ranging from the status of congestion, construction and/or maintenance activities, transit schedules, route planning, and road and weather conditions information. TxDOT has a statewide 24-hour toll-free road conditions phone number for statewide information such as construction activities and road weather conditions. Communicating by phone can be effective because the telephone can be accessed by virtually every citizen. Currently, there is a national three-digit traveler information telephone number being implemented, 511. The implementation of this number is presented in the next section.

Most state transportation agencies, and others such as regional transportation management centers, provide road weather information over the internet. These web sites provide road weather conditions along with other transportation information, and can even report this information in real-time where the technology is available. This road conditions information is also available to travelers in kiosks at public rest stops. This method of communication can be useful since traveling motorists rarely have access to the internet. Also, if travelers stop to view road weather information at a kiosk, it will allow them time to rest and could help reduce accidents resulting from fatigue.

Making Information Available to the Public

Once the road conditions data are collected, it is important to provide this information in a timely manner in a clear and easily accessible format that will benefit the greatest number of travelers. A recent study conducted in Utah surveyed the traveling public to determine what information they want and how do they want to receive this information (14). This study provided a series of questionnaires to four potential users of information from road weather information systems: commuters, recreational travelers, long-distance travelers, and truckers (including dispatchers). The results of this study show that variable

message signs (VMSs), commercial radio, and highway advisory radio are the most popular forms of delivering roadway conditions information during adverse weather. Commuters and recreational travelers prefer commercial radio, highway advisory radio, television, and variable message signs to e-mail, internet, and pager options. Long-distance travelers have similar preferences, but indicated they also prefer information to be available at information desks and kiosks.

Weather related road conditions were found to be most important to truckers and the recreational travelers. Surface conditions information was most important to truckers and the long-distance traveler. These surveys found that truckers prefer to receive road weather conditions information from three hours before departure to en route. Recreational travelers and commuters desire this information while either in route or one hour before departure. The conditions that were determined to be most important to users are related to diminishing vehicle performance and travel speeds, such as accumulating snow, ice, high winds, and road closures.

511 – Traveler Information Number

The telephone is one communication medium that is available to virtually everyone in the United States. Recent deployments of new technology in many regions of the United States have led to improvements in the collection of road conditions information, but a lack of consistency remains in terms of the quality and content available on the existing traveler information services. The sheer “number of numbers” adds to people’s confusion about where to call to receive the accurate and timely traveler information they need. In an attempt to consolidate all these traveler information numbers, the work toward one national number began. In March, 1999, the United States Department of Transportation petitioned the Federal Communications Commission for a three-digit number to be used for traveler information services. This petition was supported by 17 stated departments of transportation, 32 transit operators, and 23 metropolitan planning organizations and local transportation agencies (*13*).

The 511 traveler information number provides an easier method for the public to obtain road conditions information since there is only one phone number to remember. Also, with 511 motorists can expect to receive considerably more route-specific information than can be heard in a 30-second traffic news slot, and this information can be accessed on demand. Motorists are able to access basic travel information, such as weather and road conditions, traffic updates, and public transportation schedules, free of charge. Some 511 services may charge for additional, premium information, such as tourist information, special events, parking locations, trip routing and planning, but the caller will be notified in advance of any charges relating to information (*15*).

Currently, there are 16 states or regions that have deployed the 511 telephone number and have it operational. Another 31 states or regions have received funding under the 511 Planning Assistance Program. This program provides federal funds to help states or regions prepare their 511 deployment plan, design the system, and other steps necessary to get the 511 system operational. Other than the federal funding provided for the planning stages of implementing 511, states are not offered financial assistance. Money for the service typically comes from states transportation budgets, but finding money for other FCC-designated extensions is not as difficult. For example, the 911 emergency line and the 411 information line are funded by fees placed on telephone customers’ monthly bills (*16*).

Texas is one of the states that has received funds from the 511 Planning Assistance Program, but the state does not currently have the 511 system operational. Officials in Texas determined it would cost approximately \$2 million to implement 511 statewide, far more than the Texas Department of Transportation was willing to spend. Transportation officials debated whether to offer a pared-down 511 service but decided against it. The state already has a toll-free number for road construction and weather updates. Al Kosik, a traffic management engineer with the Texas Department of Transportation, oversees Texas’ 511 service. In a statement given to the Fort Worth Star Telegram (*16*), Mr. Kosik stated, “We could convert that 800 number to 511 fairly inexpensively, but a good traveler information system ought

to provide more than what we (TxDOT) provide more than what we provide with our 800 number...We would want people to go thru a menu by voice response...and find the roads they care about.” It is expected that the 511 system in Texas will be operational by 2004 or 2005 (16).

SURVEY OF STATE TRANSPORTATION AGENCIES

As a part of this research, state transportation agencies and other agencies, such as universities and research institutes, were surveyed to obtain information about current road weather conditions information systems. This survey was sent via e-mail or conducted by telephone. A brief description of the survey purpose was given at the top of the survey form. The survey consisted of eight questions, some of which were:

- What methods are used to collect the road conditions information on site (in the field)?
- What means of communication is used to send this information from the site to a centralized location?
- How is this information disseminated to the traveling public?
- Typically, how long does this process take?
- How often is this road conditions information updated?
- Does your agency have any plans to update its current system?

The information obtained from the surveys provided a portion of the information that is in the following section. The complete survey form is in Appendix A of this report. Agencies participating with the survey include:

- Texas Department of Transportation,
- Utah Department of Transportation,
- Colorado Department of Transportation,
- Illinois Department of Transportation,
- Montana Department of Transportation,
- Nebraska Department of Roads,
- Arizona Department of Transportation,
- University of Northern Dakota, and
- Western Transportation Institute.

ROAD WEATHER CONDITIONS INFORMATION SYSTEMS

All 50 states currently have systems in place that report road conditions to the traveling public. Each state's system is unique and some utilize technology more than others. Several states' road weather conditions information systems will be described below, beginning with Texas.

Texas

The current road weather conditions information system in Texas is termed the Highway Condition Reporting System (HCRS). This system relies heavily on individual maintenance sections for collecting road conditions information and relaying it to the appropriate district personnel. This information is entered, at the district level, into a mainframe computer which makes the information available to the public.

The initial step in this system is for local maintenance personnel to physically collect the road conditions information on-site. The road conditions information is sent to the sectional maintenance office via radio, cell phone, or whatever is the best method of communication available to the personnel on the scene. If

the adverse weather system is widespread, then maintenance personnel often rely on other agencies, such as the Department of Public Safety, Sheriff's Office, or contracted vendors to report road conditions to the sectional maintenance office (*17*). According to TxDOT's manual (*18*), "Districts must continue to report new routine conditions by 8:05 a.m., and report new emergency conditions by 8:05 a.m., 11:30 a.m., and 4:00 p.m."

Once the road conditions information reaches the sectional maintenance office, it is input in the department's CICS mainframe computer. The data has to be input by specially trained personnel into the Highway Conditions Report (HCR). Typically, there are several people in each section who are trained to input this information. The HCR is menu-driven. That is, selections for activities are made from the main menu screen. There are two ways to enter data into HCR: type it directly into a screen, or copy data from a template. The road conditions information is not updated until conditions change.

The public has two main ways to receive this road conditions information: by calling TxDOT's 1-800 Travel Information Number, or by accessing the internet site. The 1-800 number (1-800-452-9292), operated by AT&T, provides a recorded message through an automated attendant that allows the public to access general road condition information and specific road closures. This service is operational 24 hours a day, 7 days a week. New information is updated in the phone system every two hours during emergency road conditions situations if conditions are changing (*18*). When an individual access the Travel Information Number they have several options: listen to a state overview of conditions, or listen to conditions by region, city, or county. The user does not have the option of entering a road number to receive specific information.

The Highway Condition Report is also available to the public through the TxDOT web site (www.dot.state.tx.us). The TxDOT web server sweeps the mainframe four times every hour at 10, 20, 40, and 50 minutes past the hour, and uploads any new files to the web site. These new files could either be new records or any changes that were made to existing records in the mainframe version of the HCR (*18*). The TxDOT HCR web site is currently a text-based system. On the main HCR web page, the user has a choice to view road conditions reports by condition, roadways, districts, counties, or regions. There is also a list of other related areas, such as metropolitan closures, load restricted bridges, and traffic centers. When the user selects one of these options, it changes the viewing window to show either a map or a listing of roads or counties, depending on the selection made. If a map is shown in the viewing window, the user can select a highlighted area on the map to receive further information about that area. An example of the road conditions map is shown in Figure 1.

TxDOT is in the process of updating its road weather conditions information system. The most noticeable improvement will be the web site. It will be updated from the current text-based system to a geographic information system (GIS), which is similar to the web sites utilized by many other states such as Oregon, Utah, and Illinois. This GIS based web site will consist of a variety of maps of the state with depictions of roads and icons which users can "click" on and an information box will appear. This information box will provide detailed information about the conditions at the specified location. The icons will represent events such as road construction, detours, and areas of travel delays.

Although the web site will be updated, the data collection and data entry into the mainframe computer will remain basically the same. The only change to the data entry is additional GIS locator information will be required for each entry (*19*). The improvement to the web site will make roadway conditions information easier to access, but it will not help to make the available information more accurate and timely.

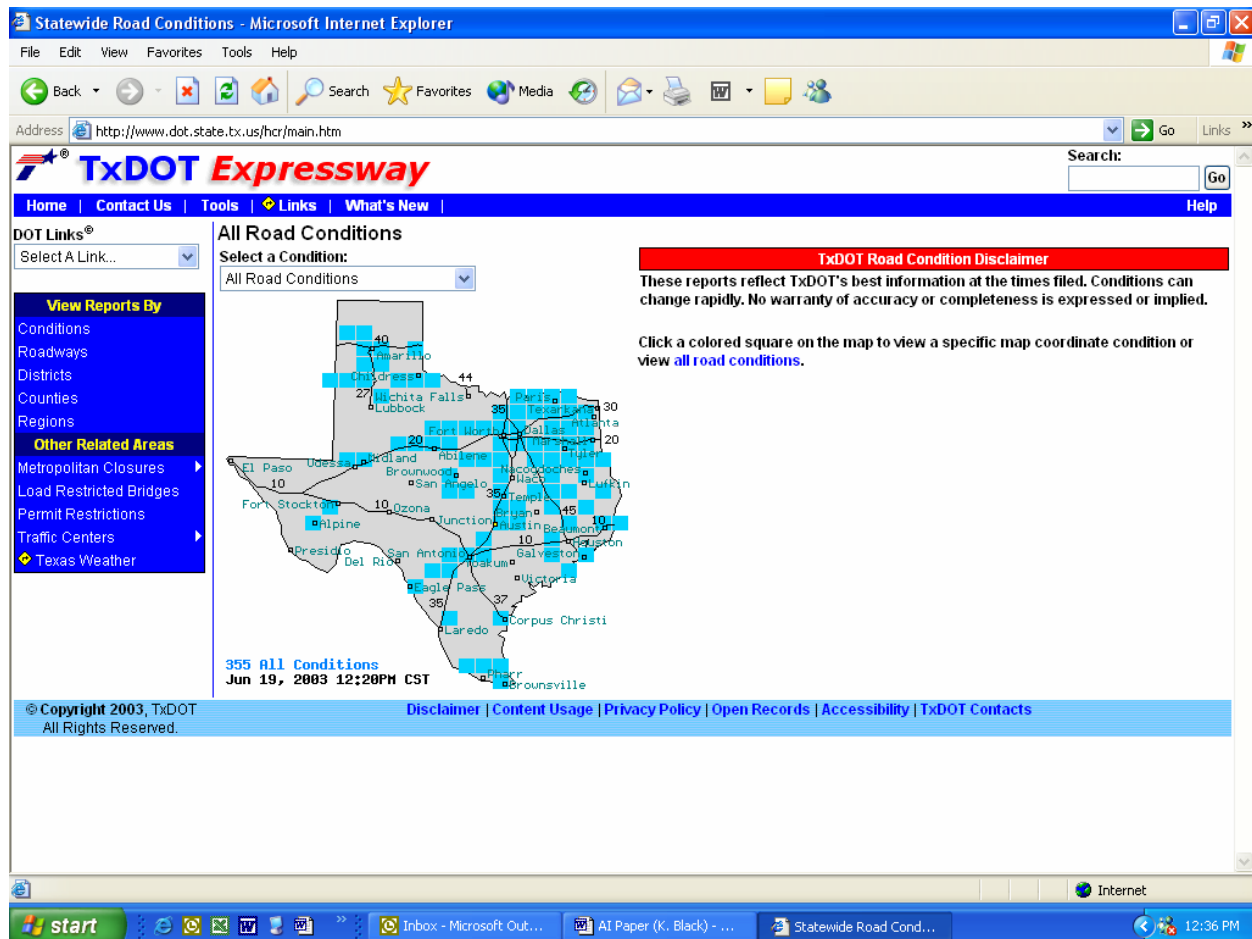


Figure 1. TxDOT Web Site Road Conditions Map

One of the main problems with the current TxDOT roadway conditions reporting system for adverse weather conditions is that the information available to the public is often several hours old, and therefore many times is not accurate. The old information that is available to the public does not allow travelers the ability to make an informed decision on their travel plans. The roadway conditions reporting system needs to be more efficient, and timely, in providing information to the public. The roadway conditions information that is collected in the field is accurate at that time, but by the time the information is available to the public, often the conditions have changed.

In a past survey of TxDOT area maintenance supervisors, 87 percent of the respondents rated the current system used for entering and transmitting the data as fairly hard or hard (20). This survey shows that there are failings in the current data entering process. Time consuming data entry is preventing the system operators from providing current roadway conditions information to the traveling public.

Utah

In 1995, the Utah Department of Transportation began working with a Traffic Management Committee, which was established by the Utah Senate, to implement Traffic Management Systems on state highways. This committee recognized the benefits of using Intelligent Transportation Systems (ITS) to manage traffic flow and improve roadway efficiency. This committee made possible CommuterLink, a computer-controlled system designed to monitor traffic flow on freeways and surface streets. This system utilizes

closed-circuit television cameras, electronic roadway signs (ERS), the 511 Traveler Information Line, pavement sensors, weather sensors, and other ITS technologies (21).

Road weather conditions information is provided to the public by CommuterLink. The on-site road conditions information is collected either by snowplow maintenance operators or by Road Weather Information Systems (RWIS). The maintenance personnel in the field call in the road conditions reports using cell phones. Utah has 52 RWIS sites located around the state which use fiber optics, radio, cellular phone, or landline telephone and modem to send road weather conditions from the field. It typically takes less than two minutes to make information available to the public once it has been reported, and the information is updated as conditions change or a minimum of two times per day (22).

Road conditions information is disseminated to the traveling public via the CommuterLink website and the 511 Traveler Information Line. Currently, only the road weather conditions reports from maintenance personnel are reported to the public. The RWIS data are for internal use only. The website shows a map which the user can zoom in/out to view a particular area. Users have the option to display the locations where there are closed-circuit television cameras, electronic roadway signs, incidents, construction, planned construction, and weather conditions. Each of these options has an individual icon which appears on the map and when selected by the user specific information will appear. An example of a CommuterLink map is shown in Figure 2. The map in Figure 2 is zoomed in to show the Salt Lake City region.

The Utah Department of Transportation is currently exploring ways to improve the CommuterLink system. One improvement being considered is providing the public with information obtained from RWIS sites. Currently, this information is only for internal use within the Department of Transportation. The system could also be improved by providing weather forecast information. One of the biggest challenges for the CommuterLink system is getting the maintenance personnel to remember to call in and report the road weather conditions (22). A more automated system would not rely on maintenance personnel reports as much as the current system.

Colorado

The Colorado Department of Transportation's Advanced Traveler Information Unit is responsible with providing the traveling public with timely information about the state's interstates, U.S. and state highway systems. The Advanced Traveler Information Unit collects information on road and weather conditions from sources across the state. This unit also collects information on major incidents.

The road and weather information is collected on-site primarily by the Colorado State Patrol and other public safety agencies, such as Colorado's port of entry personnel. The Colorado Department of Transportation's maintenance units also collect road conditions information. Typically, this is done by maintenance supervisors or snow-plow operators. To communicate this information to the Advanced Traveler Information Unit, the Colorado State Patrol uses the Colorado criminal investigation computer (CCIC). The Colorado Department of Transportation maintenance personnel typically use phone or e-mail. Other methods of collecting road and weather conditions information include closed circuit television cameras (CCTV), satellite weather systems, and surface system sensors, such as Road Weather Information Systems (RWIS). Colorado Department of Transportation's goal is to make this information available to the public is less than ten minutes (23).

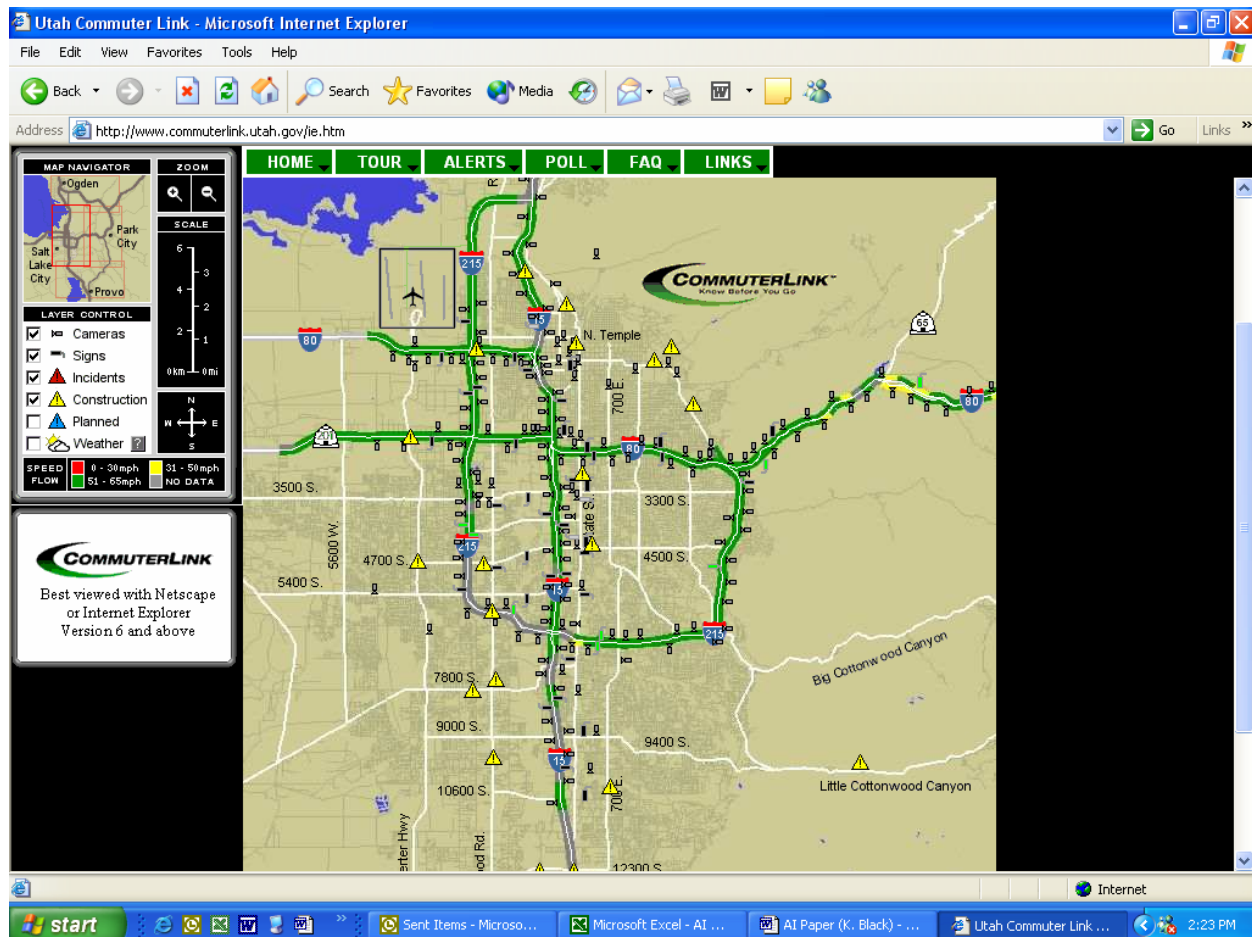


Figure 2. CommuterLink Website Map

The Advanced Traveler Information Unit compiles the road and weather conditions information into a form that is usable by the traveling public. This information is disseminated to the public in multiple ways including the internet, highway advisory radio, Voice Mailbox System Telephone Hotline, dynamic message signs (DMS), and Broadcast Fax System. The internet website (COTrip.org) provides information including road alerts updating changing conditions, accidents, chain restrictions, road closures, etc. Over a four day period during March, 2003, this website received over 25 million visits. This website is primarily text-based system and is unwrapped for use on wireless personal digital assistant (PDA) or web enabled cellular phones. There are 15 highway advisory radio units that relay road and weather conditions information to the public. These units are capable of broadcasting recorded messages or live broadcasts. The Voice Mailbox System Telephone Hotline is a toll-free statewide number that provides real time road and weather conditions including chain restrictions and road closures due to accidents or adverse weather. The caller can select to hear a statewide general report, a desired region and roads, commercial carrier alerts, or other information. There are approximately 140 dynamic message signs statewide to alert motorists of heavy traffic, hazards, chain restrictions, closures, and to provide alternate routes and parking information. The Broadcast Fax System sends a two-page road and weather report to over 200 customers in less than ten minutes. This report contains information for more than 100 Colorado cities, and lists current road conditions. During the winter, this report is issued four times daily (23,24).

The Colorado Department of Transportation is currently working to build an integrated system comprised of a graphical user interface (GUI). This would allow the various stand alone systems to work through a common platform. Colorado and Utah have similar problems in that information from the field is not as timely or as accurate as it could be. According to Mr. Mead, this is because the personnel at the scene during an event are not always thinking about calling into a control center to get the information to the public (23).

Illinois

The Illinois Department of Transportation utilizes Road Weather Information Systems (RWIS) and inspection by field crews to collect weather related road conditions information. The district offices receive this information from the field from the field crew drivers by radio. The reports are sent by fax from each district office to the state headquarters in Springfield. The RWIS sites are polled using dial-up telephone. The districts are required to provide road conditions information every two hours. The RWIS sites only send weather data upon polling. During the winter, each site is polled every 15 minutes. Polling occurs every two hours in the summer (25).

The road weather conditions information is made available to the public via the internet and a statewide toll-free telephone number. The internet (www.dot.state.il.us) contains a state map that displays the RWIS locations. The user can select one location and specific information, such as air temperature, average wind speed, wind direction, precipitation, and more, will be displayed. Also displayed is information from surface sensors that tells the location of the sensor, such as bridge deck east bound driving lane, and the pavement temperature. The RWIS site map and specific site weather information for one RWIS site is shown in Figure 3. There is a separate map on the web site that reports interstate road conditions, and they are also available at the toll-free telephone number (1-800-452-4368). The information available via telephone is a pre-recorded message that gives the user several options to choose from, such as road conditions information, and road construction activity.

Conditions reports on the web site and the pre-recorded phone message are updated every two hours, typically. The systems will be updated at other times if districts report a change in conditions; however, that is not a common occurrence. Once new information is received, it typically takes less than ten minutes to update the internet server and the phone recording system (25).

The Illinois Department of Transportation will be replacing the toll-free phone system with the 511 Traveler Information Line in the near future. This will eliminate the voice recordings and use the more user friendly speech synthesis technology. According to Mr. Peters, they would also like to add information on primary routes to the internet maps. The Illinois Department of Transportation has been supplying road conditions reports directly to public broadcast radio stations. This joint effort with broadcasters has been positively received by the public (25).

Montana

The Montana Department of Transportation's road conditions information is collected by winter maintenance staff observation and also by Road Weather Information Systems (RWIS). The winter maintenance staff communicates the road conditions information to the appropriate division office via a two-way radio system. The 59 RWIS sites located throughout the state provide real-time roadway conditions information through phone line communication (26). Road condition information is updated Monday through Friday at 6:30 am and 2:30 pm, weekends and holidays at 6:30 am, or as major changes occur (27).

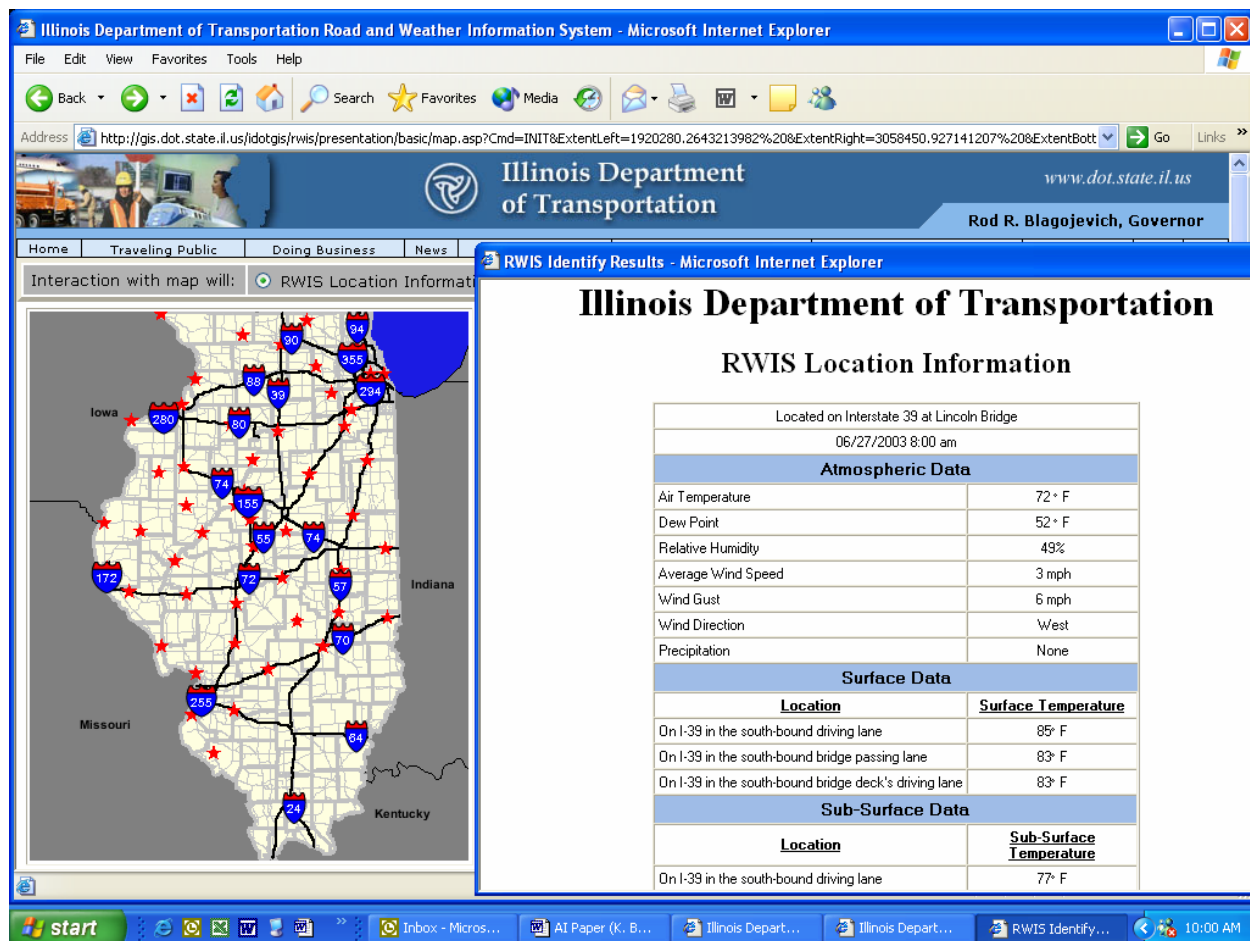


Figure 3. Illinois RWIS Map and Specific Site Information

Montana makes its road weather conditions information available to the public via local recordings, the traveler information web site, radio stations, 511 Traveler Information Line, fax, and e-mail distribution (27). The traveler information web site allows users to view images from roadway cameras, get information from specific RWIS sites, view regional maps depicting road conditions and hazards, view a regional or statewide text report of road conditions, and other options. The locations of roadway cameras and RWIS sites are shown as icons on a statewide map. The user can select the desired icon and additional information will appear. This map is shown in Figure 4.

The 511 Traveler Information Line was implemented in the 2002/2003 winter season in Montana. It provides callers the option of receiving highway road conditions information for Montana, North Dakota, South Dakota, or road weather information in other states. Within the Montana highway road conditions option, the caller can input a specific highway number, and particular section of that highway. This information is given along with the time the information was current. The winter traveler information web site and the 511 Traveler Information Line are updated every 30 minutes, or as major changes occur (26).

The Montana Department of Transportation has plans to enhance the 511 Traveler Information Line to provide road conditions information for more state-maintained highways. This enhancement would also include providing national park information, and eventually tourism information via the 511 Traveler Information Line. Montana Department of Transportation is updating the traveler information web site to

include this information as well. Also, Montana would like to replace the current local recorded messages with automated regional reports available on the 511 system (27).

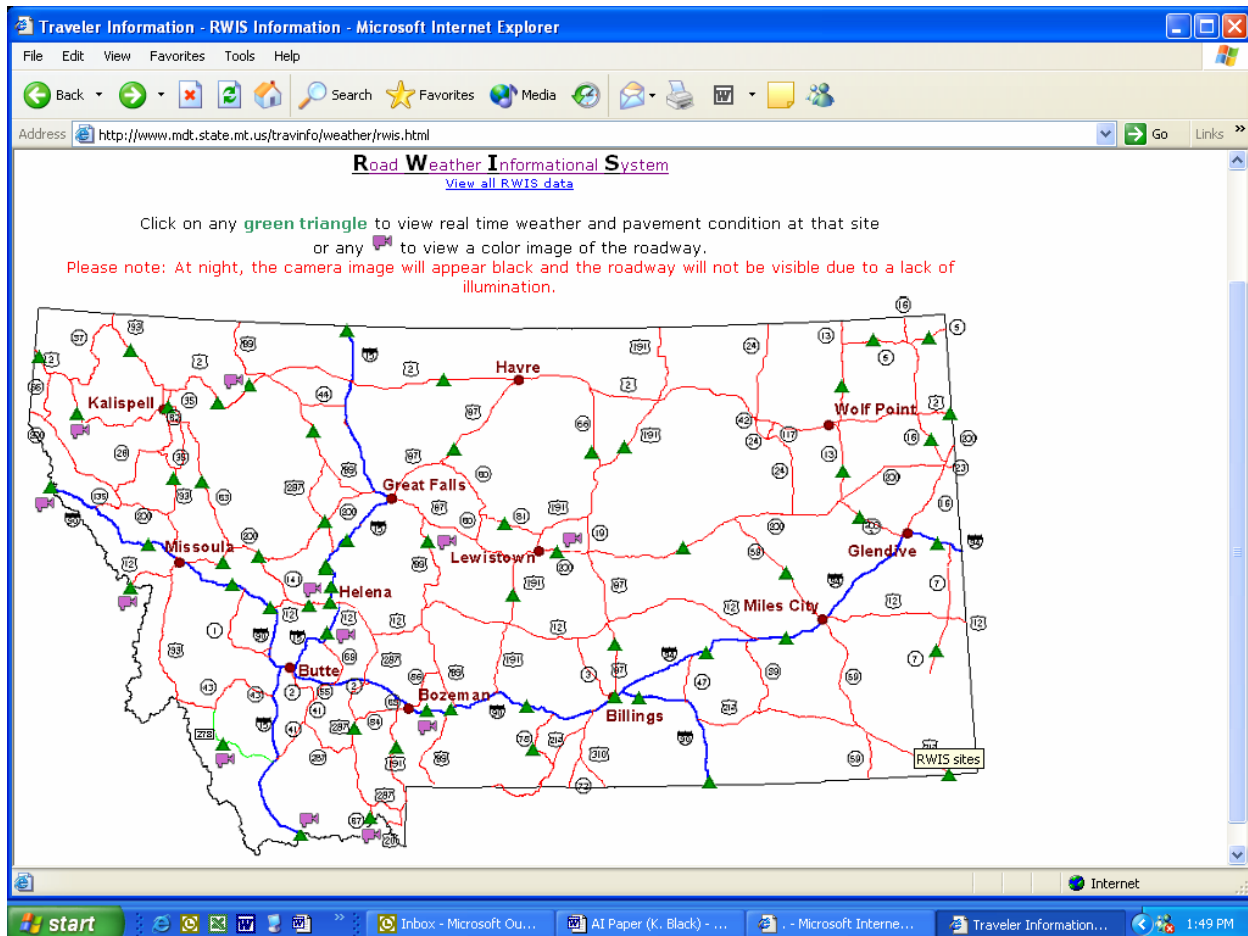


Figure 4. Montana Roadway Cameras and RWIS Site Map

Nebraska

The Nebraska Department of Roads relies on its highway maintenance supervisors and their staff to collect road weather conditions information. The maintenance personnel may choose to drive to the maintenance office or phone in the information to the maintenance office. At these locations, the data are entered into the automated road condition reporting system, which resides on the Nebraska Department of Roads' computer network. Information can only be entered into the automated road conditions reporting system from inside the network. It is possible to enter information via the internet if the authorized user has pre-approved access to the network from their home or laptop computer. This internet access requires software that is licensed through the Nebraska Department of Roads (28).

The roadway conditions information during adverse weather in Nebraska is available to the public through the 511 Traveler Information Line, which is accessible via telephone and the web. Data from the automated road condition reporting system is provided to the 511 service provider along with data from the Road Weather Information System (RWIS) stations. The 511 service provider uses information from the RWIS stations to formulate site-specific weather forecasts. The 511 service updates information on its system every five minutes, but reporting delays can occur in the field and the maintenance office.

Delays in the field can include whether or not the maintenance personnel can immediately phone in the road conditions information or do other responsibilities have priority, such as snow plowing around a stalled vehicle. Delays can also occur in the maintenance offices. These can include the appropriate personnel can not immediately input the data into the automated road condition reporting system or the computer network is not operating at full speed (28).

The Nebraska Department of Roads web site contains a link to travel and weather information. Users have the option to view current travel delays and closures, 511 Travel Information on the web, construction detours and delays, Weather Central – radar, forecasts, and more, and other options. The 511 Travel Information link on the web first shows a map of the United States with an option to view conditions in five states: Minnesota, Montana, Nebraska, North Dakota, and South Dakota. When the user selects one of these states, a map of the state appears which depicts cities and highways. The user can click any location on the map and receive road conditions information for that specific roadway as well as weather forecasts information. Figure 5 shows this map for the state of Nebraska. On the right side of the map is the specific road conditions information and weather forecast for the selected section of roadway. This web site is maintained by Meridian Environmental Technology, Incorporated.

Nebraska Department of Roads is in the process of updating their automated road condition reporting system using the Highway Condition Reporting System (HCRS) designed by Oz Engineering of Phoenix, AZ. Some of the reasons Mr. Huber (28) listed for updating the Nebraska system were: to improve the reliability of the system, to provide both the public and the internal users with more information faster and with greater detail, and providing a better means of data archiving for reporting and analysis. Nebraska is also researching methods for field reporters to directly enter road conditions information into the system from the field. This will minimize the number of people who must communicate the information before it is entered into the system. Nebraska has been working to improve this communication for years, but the information from a first person report remains the most reliable data available (28).

Arizona

The Arizona Department of Transportation is in the process of updating their road weather conditions reporting system. Once this project is complete, which is expected to be fall 2003, road conditions information will be collected in the field by RWIS sites with ambient condition sensors and still frame photos from roadway cameras. Data from the RWIS sites will be communicated via telephone, both land line and cellular. This information will be entered into the state's Highways Conditions Reporting System and made available to the traveling public via the 511 Traveler Information Line and the web site (www.az511.com). The road conditions information will be updated as often as the RWIS sites are polled. Polling rates are likely to range from 15 minute intervals to three hours, depending upon the current weather conditions (29).

Oregon

Trip Check is the Oregon Department of Transportation's roadway conditions information system. This system provides information to travelers on incidents and road condition information and also utilizes more than 120 roadway cameras. This information is accessible via phone or the internet.

Incident and road condition information is entered directly into Trip Check from ODOT regional offices around the state. The Highway Travel Condition Reporting System (HTCRS) software package, developed by ODOT, collects the data and delivers it to the web. This information is updated on a continual basis as road conditions change (30).

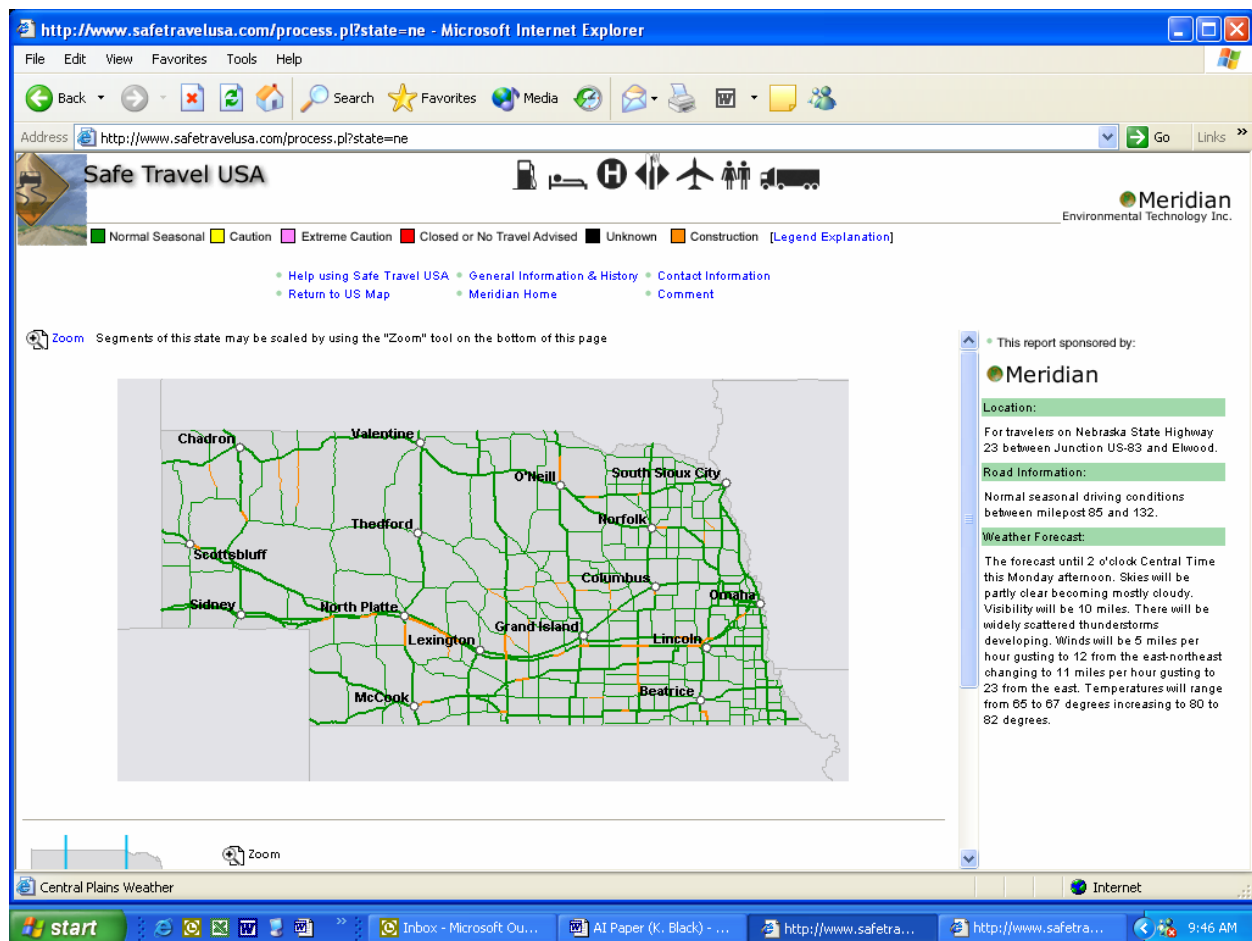


Figure 5. Nebraska Road Weather Conditions Web Site

Trip Check information can be accessed by phone (1-800-977-ODOT) or the internet (www.tripcheck.com). The phone system is automated and gives the user four choices on the main menu. The user can receive road conditions information by route or by region. The other two choices on the main menu allow the user to access the tire chain requirements and to receive information on the upgraded road conditions report system. The internet site offers users many more options. It has roadway incident maps, divided into nine regions and seven cities, which have icons to show where incidents have occurred and an estimation of travel delays. The incident maps also include icons for construction work sites, road closures, roadway cameras, information from RWIS sites, and trucking information. When an icon is selected, specific information linked to it will appear. An example of the northwest region's incident map is shown in Figure 6.

Trip Check has over 120 road cameras that travelers can access via the internet. Of the 120 cameras, 45 are located in rural areas, such as mountain passes, where knowing road conditions can be crucial to safety. The system allows users to directly link to images from the cameras. Also, users can create one, or more, custom web page with up to five camera views. These custom web pages can be bookmarked by the user for future reference. Typically, the cameras views will update several times each hour. The cameras located in the Portland area communicate with the Trip Check network via fiber optic cables. In rural areas, the cameras communicate by a frame relay system or by a phone connection utilizing a modem (30).

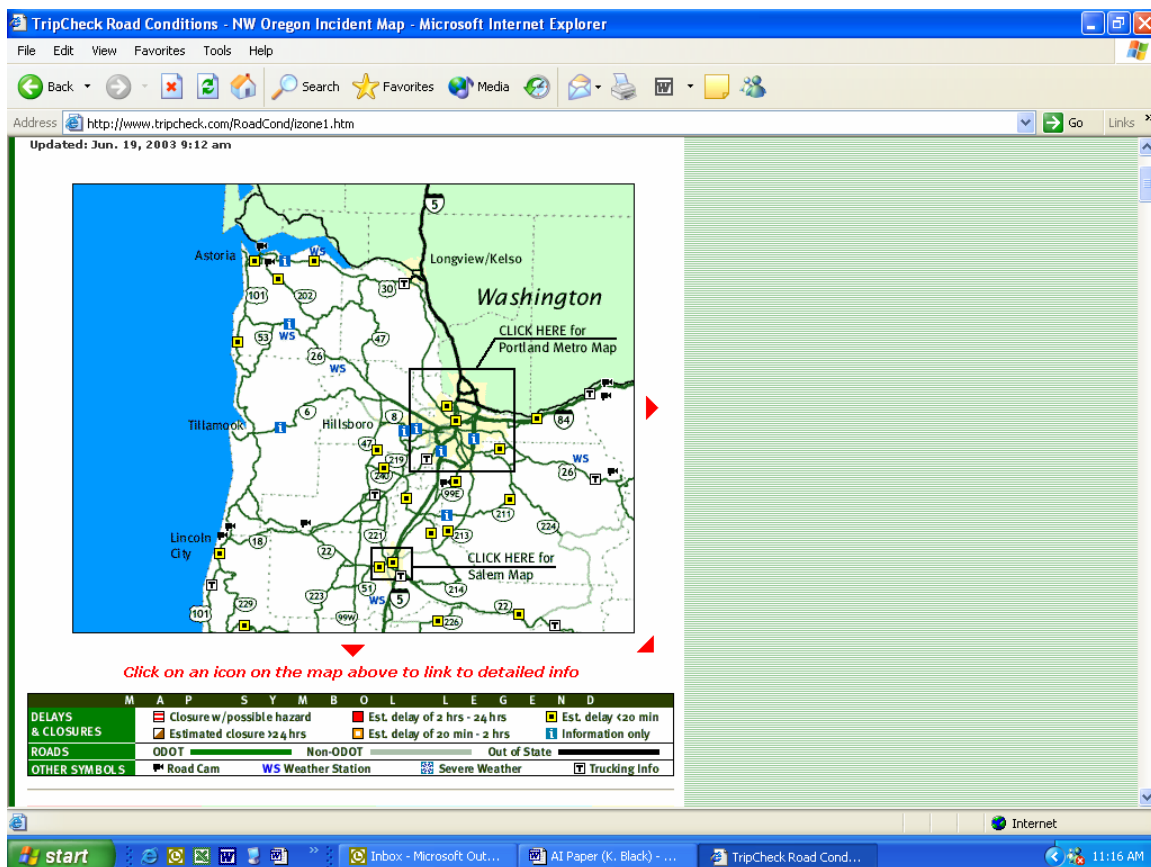


Figure 6. Trip Check Roadway Incident Map

In 2002, the Oregon Department of Transportation Trip Check web site received a national award from the Federal Highway Administration (FHWA) for being a top web site that provides vital safety and congestion information to travelers. In a press release posted on the Trip Check web site (30), Mary E. Peters, a FHWA Administrator, described the award. Ms. Peters said, “These outstanding sites were chosen because of their ‘user friendliness,’ comprehensiveness of information, and real-time reporting. Reliable, accessible traveler information helps relieve congestion and improve safety by giving travelers and shippers the information they need to choose the best time, route, and even mode of transportation.”

UPDATING TXDOT’S ROAD WEATHER INFORMATION SYSTEM

An effective statewide road weather conditions information system requires a substantial amount of road conditions information to be collected, and a means to make this information available to the public. The information must be timely, accurate, and from a reliable source. There are several improvements that could be made to the current road weather conditions information system in Texas. The following recommended improvements have been developed by analyzing the results of the survey and from the findings in the literature review.

Suggested Improvements

Update Field Reporting System

Currently, maintenance personnel are responsible for collecting road conditions information on site. This is a reliable and maybe the most accurate method of road conditions information collection, but requires a

lot of man-hours and annual expense. There are certain locations, such as flood prone sections of roadways and roadways where icing regularly occurs, which could utilize applications of technology to report road conditions information to a centralized location. Selective use of Road Weather Information Systems (RWIS) and high water detection systems would not create a considerable expense and would allow maintenance personnel to spend time at other locations. It is recommended that each district produce a list of prioritized locations where applications of such technologies would be most useful. Sites could be selected from these lists as funds are available.

TxDOT already utilizes a limited number of RWIS stations and high water detection systems, but this information is not typically disseminated to the public. The high water detection systems, typically, are linked to some type of warning sign in the immediate area, but are not linked to the statewide information system. Information from the RWIS stations is usually only available to maintenance personnel. It is suggested that select information from these technologies be made available to the public. The information from RWIS sites would have to be cleaned-up to allow the public to view it, since currently this information is in a form that may not be easily understood by the traveling public. RWIS sensors provide road conditions information only for the immediate area, but this information would supplement reports from maintenance personnel. If this information is available to the public, it is important to make certain that each RWIS station is reporting accurate information.

A method to input RWIS data to the statewide mainframe computer system needs to be developed in order to provide RWIS data to the traveling public. Houston Transtar has an effective system for disseminating data from RWIS sites to the traveling public. This system could be used as a model, or starting point, for a statewide system. The public can view the information via the web site (www.hcoem.org/txdot/). This site allows the user to select the type of weather information to view, such as rainfall amounts, flooding, air temperature, pavement temperature, wind speed, or humidity. Once the user decides which weather information to view, specific sites can be chosen from a map and that type of weather information is shown.

Improve Procedure for Information Input into Mainframe

Once accurate road conditions information is collected in the field, it is necessary to input this information into the Highway Condition Reporting System in an effective and timely manner. The roadway conditions information that is collected by maintenance personnel is accurate at the time it is recorded, but by the time the information is made available to the public, it is often several hours old and occasionally no longer accurate.

The procedure for inputting the information in the system needs to be uncomplicated and the system needs to be reliable. If the personnel responsible for entering information into the system has trouble using the system or the system is unreliable, then the information may not ever get entered into the system. The number of people who must first touch, or communicate, the information before it is entered into the system needs to be minimized. The Nebraska Department of Roads has been attempting to minimize the number of people who have to communicate the information because a first person report is still the most reliable data available (28).

It would be ideal if the Highway Condition Reporting System could be altered so that maintenance field reporters could directly enter information into the system while still out on the road. Currently, the roadway conditions information that is collected by maintenance personnel has to be communicated by cellular phone or two-way radio from the field, or the personnel can return to the maintenance section office with the information. Then, a specially trained person has to input the information into the statewide mainframe computer system. The longer this process takes, the more the actual roadway conditions will change, causing the information made available to the public to be inaccurate.

Other states, such as Nebraska, have begun to research some options for field data entry, which include using voice recognition software and entering the data via cellular phone, entering the data via personal digital assistant (PDA), or using a mobile data terminal. These types of data entry would require reliable wireless service, which is not currently available throughout all of Texas. Also, this type of data entry, most likely, could not initially be implemented on a statewide level due to the capital costs associated. Further research needs to be conducted in this area to assure that the data input is secure, but this type of data entry into the main system could be utilized in the urban areas of Texas which have dependable wireless service.

Improve Toll-free Number and Web Site

An effective road conditions information system needs to be user friendly for the traveling public. Currently TxDOT makes road conditions information available through a toll free telephone number and a web site. It is recommended that the telephone system be updated to the 511 Traveler Information Line and the web site be updated from the current text-based system to a more user friendly web site. Examples in other states such as Oregon, Utah, and Arizona, use maps with icons. When the user selects an icon, information appears specific to that location and topic. For instance, there may be different icons for RWIS sites, roadway cameras, lane closures, and road construction with each being positioned on the map in the appropriate location. This type of web site allows the user to quickly get the information that is specific to their needs without having to search through a list of information.

During the course of this research, it was discovered that TxDOT is in the process of updating both the telephone information system and its internet site. It is expected that the 511 Traveler Information Line will be operational in Texas by 2004 or 2005 (16). The 511 Line will be a large improvement over the current toll-free system. Also the current text-based web site is being updated to a graphical information system (GIS). Both of these improvements should receive positive feed back from the traveling public.

Review of Suggested Improvements

A review of the draft suggested improvements to the Texas Department of Transportation's road weather conditions information system was completed by several TxDOT personnel who frequently use the current system. Table 1 shows the individuals involved with the review.

Table 1. List of Review Committee

Reviewer	Title
Mike Alford	TxDOT, Houston District Director of Maintenance
Janelle Gbur	TxDOT, Houston District Public Information Officer
Heidi Zetty	TxDOT, Road Conditions System Manager

The review committee, for the most part, agreed with the draft recommendations. The main suggestions were that if data from RWIS sites was disseminated to the traveling public, verification of the information would be required. Also, RWIS data would have to be formatted so that it was understandable by the public. It was also stated that the TxDOT Travel Division has discussed implementing a procedure to input roadway conditions to the mainframe computer from the field, but fiscal restrictions have posed a problem. Also, a secure method of communication is a concern.

CONCLUSIONS

Adverse weather can quickly degrade the conditions of a roadway. It is important that the traveling public be informed when adverse weather conditions affect travel. State transportation agencies need to have an effective procedure to collect road conditions information and disseminate this information to the public, all in a timely manner. It is important that the information be accurate and presented in a manner that is useful to the traveling public, such as through a web site, the 511 Traveler Information Line, and commercial radio.

ITS technologies, such as Road Weather Information Systems (RWIS) and high-water detection systems, can be used to make the road weather conditions reporting systems more automated. These technologies do require large capital investments to be made, but past case studies determined that it was cost-beneficial to implement these systems at select sites (8). When using automated systems to report road weather conditions to the traveling public, it is important that regular maintenance and sensor calibrations be completed on these systems to ensure the information provided to the public is accurate.

The suggestions listed for TxDOT's road weather conditions information reporting system will, if implemented, make the current system more efficient and effective. These improvements most likely will not be able to be implemented immediately, due to limited funding and the need for additional research specifically in the area of data collection. The recommended improvements are:

- Update field reporting system – Utilize ITS technologies, such as RWIS and high water detection systems, at selective locations,
- Improve procedure for information input into mainframe – Reduce the time it takes to get roadway conditions information from the field to the traveling public. Data entry to the mainframe from the field would be ideal, and
- Improve toll-free number and web site – Update toll-free number to the 511 Traveler Information Line and update the web site to a more user-friendly GIS-based system.

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- Brian Chamberlain, ATIS Project Manager, Utah Department of Transportation,
- Janelle Gbur, Houston District Public Information Officer, Texas Department of Transportation,
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- Jaimie Huber, ITS Project Manager/511 Operations Manager, Nebraska Department of Roads,
- David Lively, Caltrans,
- Rodrick Mead, CTMC Operations Manager, Colorado Department of Transportation,

- Tim Peters, Equipment Engineer, Illinois Department of Transportation,
- Brandi Tesch, Traveler Information Specialists, Montana Department of Transportation,
- Marian Thompson, ITS Project Manager, Arizona Department of Transportation,
- Tim Wolf, Arizona Department of Transportation, and
- Hiedi Zetty, Road Conditions System Manager, Texas Department of Transportation.

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APPENDIX A: SURVEY DOCUMENT

Road Weather Conditions Information System Survey	
Name:	
Title:	
Agency:	
Address:	
Phone:	
E-mail:	
Weather has a considerable safety, mobility, and economic impact on transportation. Drivers are often faced with many unexpected situations when adverse weather conditions occur. Adverse weather conditions create potentially unsafe conditions on the roadway and often cause travelers to be delayed or travel to be postponed due to road closures. Transportation agencies have the responsibility of informing the traveling public of hazardous roadway conditions when they occur. The purpose of this survey is to obtain information about your agency's road weather conditions information system with respect to collecting the roadway conditions information and disseminating the information to the public. Please complete and return this survey by e-mail (k-black@ttimail.tamu.edu) or fax (979-845-6006) to Kit Black by July 9, 2003. If you have any questions, or additional comments, direct them to Kit Black either by e-mail, fax, or phone at (979) 862-8492. Thank you in advance for your participation.	
What methods are used to collect the road conditions information on-site (in the field)?	
What means of communication is used to send this information from the site to a centralized location?	
How is this information disseminated to the traveling public?	
Typically, how long does this process take (From the time the information is collected on-site until it is available to the public)?	
How often is this road conditions information that is available to the public updated?	
Does your agency have any plans to update its current system and if so could you briefly explain?	
In your opinion, are there any improvements that could be made to your agencies current system? If so could you briefly describe these improvements?	
If you were to design a state-of-the-art road weather information system for a state for the purpose of getting information to the public, what technologies, and procedures would be most useful?	

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Kit R. Black is currently pursuing his Master of Engineering degree in Civil Engineering at The Texas A&M University. He is expecting to complete this degree in December, 2003. While in the Master's program, Kit is a Graduate Assistant Researcher at Texas Transportation Institute (TTI). He is an active member of the student chapter of the Institute of Transportation Engineers.

Kit received his B.S. in Civil Engineering from The Texas A&M University in December 2002. While at Texas A&M, he was a member of the student chapter of the American Society of Civil Engineers where he was apart of the concrete canoe team. Kit was fortunate to be awarded the "Perch" Hill '13 scholarship for the 2002/2003 school year. He was also inducted into Tau Beta Pi engineering honor society in 2002.

Kit began his college career at Amarillo College in Amarillo, Texas, where he was awarded a partial scholarship from the National Honor Society. He was inducted into Phi Theta Kappa honor society while at Amarillo College. He also received the Outstanding Major in Engineering award in 2000.

Mr. Black has worked for the Texas Department of Transportation (TxDOT) and TTI at times throughout his college career. He was a field inspector during the summer of 2001 at the Amarillo Area Office of TxDOT. There he monitored contractor's progress and insured that completed work adhered to plans and state standards. In the summer of 2002, Kit was accepted to participate in the Undergraduate Fellows Program. As a part of program, he worked directly under a researcher at TTI to evaluate the effects of freeway congestion on mobile source emissions. This was an excellent opportunity for him to gain useful research experience. After the Fellows Program ended, he continued to work part-time at TTI in the transportation planning group.

His interests in the field of transportation engineering include signal operations, geometric design, and roadway safety.

