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16. Abstract This document is the culmination of the twelfth offering of a Mentors Program at Texas A&M University on Advanced Surface Transportation Systems that was presented in 2002 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. In 2002, the Program was available to state Department of Transportation employees as well. 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 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.					
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**COMPENDIUM:
PAPERS ON
ADVANCED SURFACE TRANSPORTATION SYSTEMS
AUGUST 2002**



Class Instructor and Mentors (front row, from left) Conrad Dudek, Jack Kay, James Wright, Thomas Werner; (back row) Wayne Shackelford, Walter Kraft, Gary Trietsch

PREFACE

This document is the culmination of the twelfth offering of a Mentors Program at Texas A&M University on Advanced Surface Transportation Systems that was presented in 2002 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. In 2002, the Program was available to state Department of Transportation employees as well.

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.

Jack Kay, 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 2002 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.

Conrad L. Dudek

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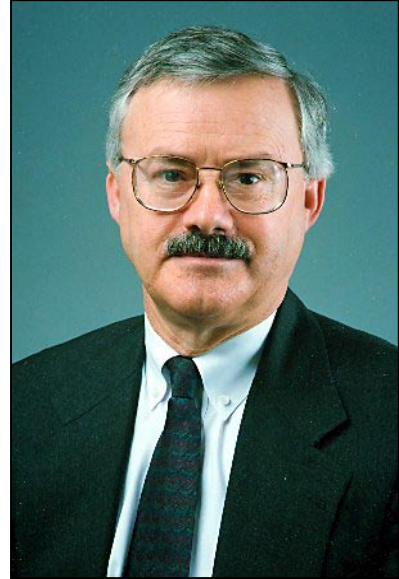
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2002 MENTORS**JACK L. KAY**

Mr. Jack L. Kay is a retired transportation consultant with a specialty interest in the application of technology to aid in solving complex transportation problems. Prior to his retirement, Mr. Kay served as Executive Transportation Advisor to the transportation sector of Science Applications International Corporation (SAIC). Prior to that, he was CEO and Chairman of JHK & Associates (which became a wholly owned subsidiary of SAIC). In that position he managed the firm's nationwide transportation practice, which included a major interest in ITS activities. The firm is now a part of TransCore, a national transportation and toll consulting and integration firm.

The firm's projects included computerization of traffic signals throughout New York City, Los Angeles, San Jose, Anaheim, Portland, Charlotte, Raleigh, Baltimore, and numerous other cities throughout the United States. The firm also provided consulting and operations services in corridor and freeway management, including the Los Angeles Smart Corridor, the New York INFORM system, enhancements to the Atlanta regional system, and portions of the I-95 corridor project. The firm also conducted comprehensive regional ITS studies under Mr. Kay's administration and developed training courses for the Federal Highway Administration. He also provided direct technical consulting to the World Bank, working on transportation issues in Moscow, Manila, Bangkok, Jakarta, and several smaller cities in the Philippines.

Although retired, Mr. Kay continues to be active in the professional community where he serves on the TRB FHWA Research and Technology Coordinating Committee and chairs a committee for FHWA looking at innovative technologies and processes to mitigate the impacts of construction work zones. He previously served on the Board of Directors for ITS America and chaired the board of that organization for a one-year term. Mr. Kay is the recipient of one of ITE's highest awards, the Theodore M. Matson Memorial Award.



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.

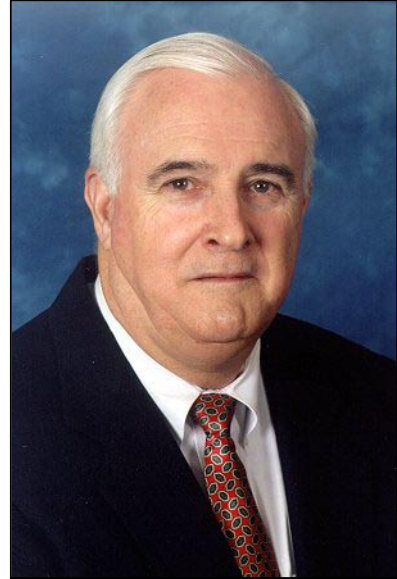
Dr. Kraft was graduated from the Newark College of Engineering with BSCE (1962) and MSCE (1965) degrees. He received the degree of Doctor of Engineering Science in 1975 from the New Jersey Institute of Technology.

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 eleven cities in nine 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 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).

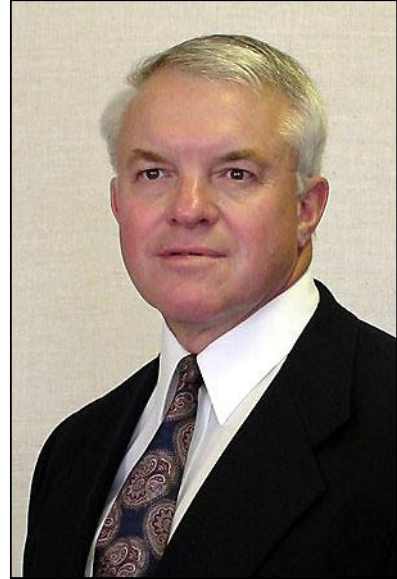
Mr. Trietsch was the Founding President of Intelligent Transportation Systems (ITS) of Texas in 1993. He is also a member of the Institute of Transportation Engineers and the National Society of Professional Engineers.

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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**DEVELOPMENT OF GUIDELINES FOR DESIGNING
A FREEWAY TRANSPORTATION MANAGEMENT CENTER BUILDING**

by

DingXin Cheng

Professional Mentor

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PB Farradyne Inc.

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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 guidelines for designing a freeway Transportation Management Center (TMC) building were developed in this paper. The guidelines will be of interest to transportation engineers and architects who will design a freeway TMC or government agencies who are planning to implement a freeway TMC.

There are not only successful experiences but also many lessons learned in building TMCs in the United States. TMCs are unique facilities. Architects and engineers who are unfamiliar with the particular aspects of TMCs, with how they are used, and with the devices and systems they contain, would often make design errors, resulting in either operational difficulties or requiring expensive rework after the TMC is completed. Therefore, a survey and interviews with fifteen TMCs in the United States were conducted and the guidelines for designing a freeway TMC building were developed.

The following steps were taken in developing the set of guidelines for designing a freeway TMC building:

- Investigated the sizes of the surveyed TMCs in the United States;
- Identified the factors that influences the determinations of the sizes of their TMC buildings;
- Found out the relationships among the size of building with its influence factors;
- Found out the successful experiences for designing a freeway TMC building;
- Found out the lessons learned from surveyed TMCs; and
- Developed guidelines for designing a freeway TMC building based upon the successful stories and lessons learned.

The main contributions of the paper are the lessons learned from the state-of-the-practice on freeway TMC design, and findings on relationships among TMC building characteristics. Especially, the author investigated the size issue of a TMC building, including the relationships among the size of the TMC building, the size of the control room, and the number of staff of the TMC based on the survey. Finally, the guidelines were developed.

This research was limited to developing guidelines for designing a freeway TMC building, not for tunnels and bridges, rail transit, railroads, or other centers. Particularly, the interest of the research mainly was focused on the determination of size issues of a freeway TMC building due to the time limits.

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INTRODUCTION

A Transportation Management Center or Traffic Management Center (TMC) is the hub or nerve center of a transportation management system. It is where information about the transportation network (freeway system, traffic signal system, or transit network) is collected and processed, and fused with other operational and control data to produce information. The information is then used by system operators to monitor the operations of the transportation system and to initiate control strategies to affect changes in operation. It is also where agencies can coordinate their responses to transportation situations and conditions. Furthermore, the TMC is the focal point for communicating transportation related information to the media and the motoring public (*1*).

A TMC equipped with many ITS functions can help to significantly reduce traffic congestion levels without adding additional miles of roadway, decrease the incident or accident detection and response times, increase communication and coordination among different agencies, and also provides some other useful functions.

WHO SHOULD LOOK AT THIS PAPER?

This paper is intended to instruct transportation engineers, architects, and government agencies who are planning to design a freeway-based TMC building in an urban area. Fifteen urban freeway-based TMCs currently operating in the United States were investigated in this paper. Many experts, who designed and/or managed a TMC, gave their valuable opinions for this research project. The guidelines for designing a freeway TMC building were developed based their opinions and literature reviews. The guidelines will help agencies planning to implement a freeway TMC and architects and engineers who want to design a freeway TMC.

WHY DO WE NEED GUIDELINES FOR DESIGNING A FREEWAY TMC BUILDING?

There are many successfully built TMCs in the United States. However, there are also some mistakes that are repeated during the design of these TMCs. An important lesson learned in TMC procurement was that TMCs were unique facilities, and that architects and engineers who were unfamiliar with the particular aspects of TMCs, with how they were used, and with the devices and systems they contained would often make design errors, resulting in either operational difficulties or requiring expensive rework after the TMC was completed (*1*). One thing that should be done is to determine how to effectively utilize the lessons learned, and how to keep from making the same mistakes again. Therefore, this paper develops guidelines for designing a new freeway TMC building by synthesizing the current state-of-the-practice.

Research Objectives

The overall goal of this research is to develop guidelines for designing a freeway transportation management center building. The guidelines will help agencies, architects, and design engineers conquer the special needs of designing a freeway type TMC building. The specific objectives of this research were to:

- Investigate the sizes of the surveyed freeway TMCs ;
- Identify the factors that could influence the determinations of the sizes of these freeway TMCs;
- Find out the successful experiences for designing a freeway TMC building;
- Find out the failures or lessons learned from the experiences of the surveyed freeway TMCs; and
- Develop guidelines for designing a freeway TMC building based upon the success stories and lessons learned.

Scope of Research

This research is limited to developing guidelines for designing TMC building for a freeway, not for tunnels and bridges, rail transit, railroads, or other centers. Particularly, the interest of the research was focused on the determination of size issues of a freeway TMC building. The pros and cons related to building a freeway TMC were identified based on survey and the interviews with fifteen TMCs in the United States.

FREEWAY TRANSPORTATION MANAGEMENT CENTER

In order to develop guidelines for designing a freeway Transportation Management Center building, the definition, benefits, and some basic functions of a freeway TMC are introduced in this chapter.

Freeway Transportation Management Center

A freeway transportation management center is typically built for the monitoring and control of traffic on an interstate highway or comparable limited access roadway. The typical freeway management center will focus its efforts on detection, verification, and active management of incidents, which reduce roadway capacity; on distribution of information to travelers; and on optimization of roadway capacity through active strategies, such as ramp metering. Additional functions, such as motorist assistance patrols, may be managed from within the freeway TMC. In a typical freeway management centers, operators receive notice of incidents through:

- A network of sensors (loop detectors, radar, etc.) which continuously monitor traffic flow (speed, occupancy, and/or volume);
- Motorist calls from roadside telephones, cellular phones, or those relayed via the “911” network;
- Vehicle “probes” such as those monitoring flow of vehicles (including passenger and commercial vehicles, transit buses, law enforcement vehicles, or maintenance vehicles), which carry radio frequency transponders or are actively transmitting their location derived from on-board global positioning systems; and
- Monitoring video images from roadside cameras.

Following notification, incidents are typically verified by on site personnel or through these roadside cameras. Incident responses vary, including notification to law enforcement, emergency services, hazardous material management, maintenance, motorist assistance patrol, wreckers, and posting of messages to approaching motorists via Variable Message Signs and Highway Advisory Radio.

Freeway TMC Expected Benefits

A freeway transportation management center adds many benefits to the Nation’s transportation infrastructure (2). The following benefits are expected from a freeway TMC:

- Better incident management in terms of reduced incident response times; incident detection times; and incident clearance times to restore normal operation conditions, limiting the possibility of secondary accidents.
- Better congestion management, traffic management, and traffic diversion in response to traffic and weather related incidents; major events; route and alternative route comparisons based on improvement and service level indicators; mitigating the effects of recurring and nonrecurring congestion through various congestion management techniques; large-scale construction activities.
- Improved information dissemination to emergency services and their vehicles; information service providers; traveling public; media; public agencies; private organizations.
- Maintained and/or improved overall safety of the transportation system.

- Reduced number of incidents and lower accident rates (including secondary accidents).
- Improved air quality through pollutant reduction; fewer vehicle emissions.
- Increased highway efficiency through transportation demand management/ system management strategies such as HOV lanes.
- Increased energy and fuel savings.
- Enhanced efficiency of the transportation infrastructure.
- More efficient snow removal operations.
- Efficient use of staffing and resources through better internal and external control; improved employee motivation and involvement; better coordination; reduction of costs.
- Safe environment for emergency personnel.
- Improved customer service through information.
- Improved public relations and interface with the public.

The following are some benefit examples from the ITS Benefits and Unit Costs Database (3) based on the version of July 8, 2002. Ramp Metering has shown a 15-50 percent reduction in crashes and an 8-60 percent increase in freeway speeds. In San Antonio, integrated VMS and incident management systems decreased accidents by 2.8 percent. The Georgia Navigator (integrated system) supported incident delay reductions for an annual savings of \$44.6 million. Delay Savings Incident management in city and regional areas has saved 0.95-15.6 million vehicle-hours of delay per year. In Palm Beach, GPS/AVL systems have reduced police response times by 20 percent.

Common Freeway TMC Functions

The commonly used functions of freeway transportation management centers are listed as follows:

Traffic Management

Traffic management is the monitoring and control of the flow of traffic of a recurring nature by the TMC. Its most common components are active flow balancing between alternative routes, provision of relative travel times for alternative routes, and ramp metering such as that used on the freeways in the Houston area (4). Control of HOV facilities is also included in this category, especially when the HOV lane is reversible (5), and its operation may include gates or relocating a movable barrier.

Incident Management

Incident management includes two components: incident prevention and incident response. In prevention, the TMC acts to avoid impact from situations that could result in incidents. Common approaches include providing traveler warnings of unsafe or congested roadway conditions, motorist assistance patrols, “push-off” bumpers on agency vehicles, roadside accident investigation sites, effective management of lane closures (often more a form of mitigation than prevention), and rapid dispatch of resources to repair road damage or to remove debris. Incident response aims to reduce the impact of an incident that has already occurred. The primary component is the rapid reduction of impact (reducing the number of lanes closed and creating alternative routes), termination of impact by incident clearance (and removal from view, if possible), and roadway cleanup. Incident management also includes providing traveler information regarding the incident (or incident impact), in hopes of reducing the number of vehicles delayed by the incident and minimizing the likelihood of secondary incidents.

Traveler Information

Dissemination of road construction, congestion, incident related information, or other highway related information to the public through highway-based information sources such as Variable Message Signs, Highway Advisory Radio, or motorist call-in services, i.e., 511 (6).

Emergency Management

Emergency management includes any activities related to the dispatching and direct involvement of TMC personnel dedicated for on-site emergencies due to catastrophes and disasters (2). Emergency management also includes coordination with emergency agencies and involves communication with or dispatching of appropriate personnel.

Fleet Management

Fleet management includes the monitoring and active management of a group of vehicles operating on the roadway. The most common component is vehicle location monitoring, either automatically (via automatic vehicle location technology) or manually (by radio contact with the vehicle operator), from which schedule adherence and vehicle headways can be determined. Active response to these parameters could include altering the duration of one or more vehicle stops, or activation of traffic signal priority.

Emission Management

Emission management includes the observation and detection of air quality, noise.

Hazardous Materials (HAZMAT) Management

HAZMAT management includes the response to incidents involving hazardous materials and communication with and/or dispatching appropriate personnel.

There are some other functions that a freeway TMC may have, such as toll collection, coordination with transit system, etc.

In order to successfully design a freeway TMC building, agencies that will stay in the building, and functions that the TMC will have, need to be determined first. The designed TMC building should meet the needs of these agencies and functions. Especially, the design of building should conquer the spatial requirement of these agencies and functions.

CHARACTERISTICS OF FREEWAY TMC BUILDINGS

Transportation management centers have their unique architecture characteristics from other traditional office buildings. A TMC center has to meet the spatial needs of transportation management systems and ITS systems.

Sizes of TMCs

Depending on the functionality and extent of activities, physical sizes and configurations of TMCs may vary significantly. For example, the big size TMC building such as TranStar in Houston, Texas is a three-story, 54,000 square feet building shown as Figure 1. The control room alone is 5,000 square feet. At large TMCs, such as TranStar (7), Navigator (8), TransGuide (9), etc., a wide variety of functions are performed and many agencies are located inside the building. Medium-sized TMCs, such as the Monitor in Milwaukee, Wisconsin (10), and Smart Traffic Center (11) of Virginia DOT cover 6,500 square feet and 7,200 square feet, respectively. Many basic functions performed in the large-sized TMCs are also performed in the medium-sized TMCs, but are generally reduced in terms of the magnitude of central equipment in the TMC or the extent of the activities to support those primary functions.



Figure 1. TMC Building TranStar in Houston, TX

Some smaller-sized TMCs, particularly a number of the Maryland State Highway Administration's TMCs, act as satellite centers and report to a larger statewide or regional center.

The major differences among large, medium, and small-sized TMCs are based on a number of considerations, some of which are listed below (*12*):

- Size and functionality of the transportation system. Generally, it has been the design approach that the larger the transportation system coverage (i.e., number of highway miles), the larger the TMC.
- Additional systems or functions co-located at the TMC. These can include police presence, equipment dispatching, HOV operations, and transit coverage.
- Number of operators on duty at any one time or on one shift, with each operator requiring a console or terminal.
- The type and layout of any video/graphic displays. Television monitors and large screen displays require a significant amount of vertical and horizontal space, particularly if projection systems are used.
- Officespace. In some locations, TMCs include offices only for staff involved with TMC management. In other TMCs, offices are also provided for additional staff with adjunct or unrelated duties.
- Number and type of specialized areas such as conference facilities, reception areas, press room(s), kitchens, restrooms, equipment and lighting rooms.

Typical Layout of a Freeway TMC

Regardless of the size of a TMC building, a typical layout includes:

Control Room

The control room is one of the most important parts of a transportation management center. It normally houses operator workstations, consoles, CCTV monitors, and in many centers, a large wall display. Use of video is a trend replacing the old graphic wall maps. Projecting the workstation's screen onto a large video display allows more related personal to clearly observe field conditions from the control room, adjacent conference rooms, or an adjacent visitor viewing room. Figure 2 shows an example of medium-sized TMC control room and Figure 3 shows an example of large-sized TMC control room.



Figure 2. The Control Room of Monitor in Milwaukee, Wisconsin



Figure 3. The Control Room of TransGuide in San Antonio, TX

Equipment Rooms

Equipment rooms are needed for housing computers, communications, peripherals, UPS, heating and cooling system, maintenance equipments, etc.

Conference/Media Rooms and Visitor/Tour Facilities

Conference or media rooms are used for communication among different agencies or within an agency itself. It could be used to make important decisions among supervisors and TMC managers. Many centers also provide visiting rooms in order to let people know the functions of TMCs.

Offices and Personal Facilities

Each agency may need its own offices for its managers or for dealing with some internal issues. The TMC managers and supervisors need their own office to be more efficiently conduct their job. The personal facilities may include breaking rooms, kitchens, bedrooms, and rest rooms.

FINDINGS ON FREEWAY TMC BUILDINGS

A survey questionnaire on designing a freeway TMC building was developed, shown in Appendix A, based on the interviews with several TMC managers, and was reviewed by the mentor (13). The questionnaire was sent to 23 TMCs in the United States. Responses were received from fifteen TMCs for an overall response rate of 65 percent.

TMCs Surveyed

The TMCs responded to the survey questionnaire are listed in Table 1(14, 15, 16, 17, 18, 19, 20). TMCs in Table 1 are sorted by the alphabetical order of the state. Based on the survey responses and data analysis, the findings of the research are presented in the following paragraphs.

Agencies Inside TMC Buildings

The number of agencies and type of agencies are very important factors affecting the designing of a TMC building. A new agency added to a TMC may need more consoles in the control room, a special room for their unique devices, and/or an isolated office to deal with internal issues. The agencies located in the surveyed TMC buildings are summarized in Table 2. From Table 2, the descending order of agencies stayed in the TMC buildings is Department of Transportation, Police, Government Agencies, etc. Some TMCs, such as TranStar, may have more agencies that are not listed in this table, such as media and private companies.

Functions Performed in TMC Buildings

The functions are very important factors affecting the design of a TMC building. The relationship between the function and agencies are cross working. For example, one agency may perform several functions, while one complex function may need the cooperation of several agencies. To provide TMC designers or planners with an idea about what functions a freeway TMC would normally have, the functions of surveyed TMCs are listed in Table 3. From Table 3, the descending order of functions of a transportation management center may have is traffic management; traveler information; emergency management; incident and special event; law enforcement; maintenance and construction management; and transit management. Some centers may have other functions according their local needs, such as NITTEC, a TMC in Buffalo, NY, having the special function of snow and ice callout (21).

Size Issues of a TMC Building

Many factors could influence the size of a TMC building. Influence factors, including the size of TMC building, total number of staff, max number of staff working at the same time, centerline lane miles, and operation hours, were collected through the survey and the results are listed in Table 4.

Based on the results of Table 4, Figure 4 is used to find the relationship between the freeway centerline lane miles and the sizes of TMC buildings. From the results in Figure 4, there is no statistically significant relationship between these two parameters. This is consistent with the finding of Kraft (2).

Now, are there correlations among the size of a TMC building, the total number of staff, and the maximum number of staff working at the same time in the TMC building? Figure 5 shows the results from the response. The size of a TMC building increases with the increasing of the total number of staff and the maximum number of staff working at the same time. The mean values of the size of TMC building per staff in terms of total number of staff and maximum number of staff working at the same time, and other statistical results are listed in Table 5. For a new freeway TMC building design, the value that is higher than the mean value of space per person is recommended as a preliminary figure. Both the

minimum value and the maximum value of space per person are not recommended because the minimum value may not be enough for TMC functions while the maximum value may cost too much.

Table 1. Surveyed Transportation Management Centers

Transportation Management Centers	City	State
San Diego Region	San Diego	CA
Bridgeport Operation	Bridgeport	CT
MITSC	Detroit	MI
Transp. Info. Center	Chesterfield	MO
NJDOT Region North	Elmwood Park	NJ
INFORM	Long Island	NY
NITTEC	Buffalo	NY
Regional TOC / Rochester	Rochester	NY
Capital Region / Albany	Albany	NY
TranStar	Houston	TX
TransGuide	San Antonio	TX
TransVISION	Fort Worth	TX
Smart Traffic Center	Hampton Roads	VA
Monitor	Milwaukee	WI
WSDOT Olympic Region	Olympic	WS

Sizes of Functional Rooms

TMCs have unique room requirements to successfully perform their special functions. Based on the survey responses and the measured floor plans, Table 6 lists the typical function rooms and their sizes where the blank in the table means that the information is not available from the survey. From Table 6, normally the bigger the control room, the larger the equipment room. However, the bigger control room doesn't mean bigger offices or conference rooms. In addition, the sizes of control rooms are related to the number of staff in the building and the max number of staff working at the same time. Figure 6 shows the direct relationship between the size of a TMC control room and the number of staff.

Table 2. Agencies Located inside TMC Buildings

Transportation Management Centers	Agencies					
	DOT	Police	Government	Transit	Fire	Research Institute
TransGuide	X	X	X	X	X	X
TranStar	X	X	X	X		
San Diego Region	X	X	X			
NITTEC	X	X		X		
INFORM	X	X				
MITSC	X	X				
Monitor	X	X				
Smart Traffic Center	X	X				
Regional TOC/ Rochester	X	X				
Bridgeport Operation	X	X				
Capital Region/ Albany	X	X				
NJDOT Region North	X					
Transp. Info. Center	X					
TransVISION	X					
WSDOT Olympic Region	X					

By dividing the room sizes of the Table 6 by the total size of their TMC building, the percentages of each function room to the TMC building are listed in Table 7. The more clear illustration for the mean value is shown in Figure 7. This information could be used as a bulk instruction to determine the size of individual type of function room(s) once the total size of the building is decided.

Table 3. Functions Performed in TMC Buildings

Transportation Management Center	Traffic Management	Traveler Information	Emergency Management	Incident and Special Event	Law Enforcement	Maintenance and Construction Management	Transit Management
TranStar	X	X	X	X	X		X
NITTEC	X	X	X	X		X	X
San Diego Region	X	X	X	X	X		
Capital Region/ Albany	X	X	X	X	X		
TransGuide	X	X	X	X	X		
MITSC	X	X	X		X		
Smart Traffic Center	X	X	X			X	
NJDOT Region North	X	X	X	X			
Bridgeport Operation	X	X		X	X		
Transp. Infor. Center	X	X	X	X			
Regional TOC /Rochester	X		X	X	X		
TransVISION	X		X			X	
Monitor	X	X				X	
INFORM	X	X	X				
WSDOT Olympic Region	X	X					

Table 4. Size of a TMC Building and Its Influence Factors

Transportation Management Center	Size of TMC Sq. ft	Centerline Lane Miles (miles)	Total Number of Staff	Max Number of Staff Working at the Same Time	Operation Hours
TranStar	54,000	290	161	130	24/7
TransGuide	54000	90	25	18	20/7
Regional TOC/ Rochester	45000	13	106	96	12/5
San Diego Region	37720	300	120	60	24/7
TransVision	29622	105	43	20	12/5
Transp. Info. Center	24000	150	38	6	18/5
Smart Traffic Center	7200	160	15	6	24/7
Monitor	6500	130	7	3	
NITTEC	3500		12		24/7
INFORM	2925	140	12	5	24/7
Captial Region/Albany	2700	50	29	10	24/7
WSDOT Olympic Region	2200	158	10	4	24/7
NJDOT Region North	1800	120	24	8	16/5
Bridgeport Operation	1200	60	15	4	24/7
MITSC		180			24/7

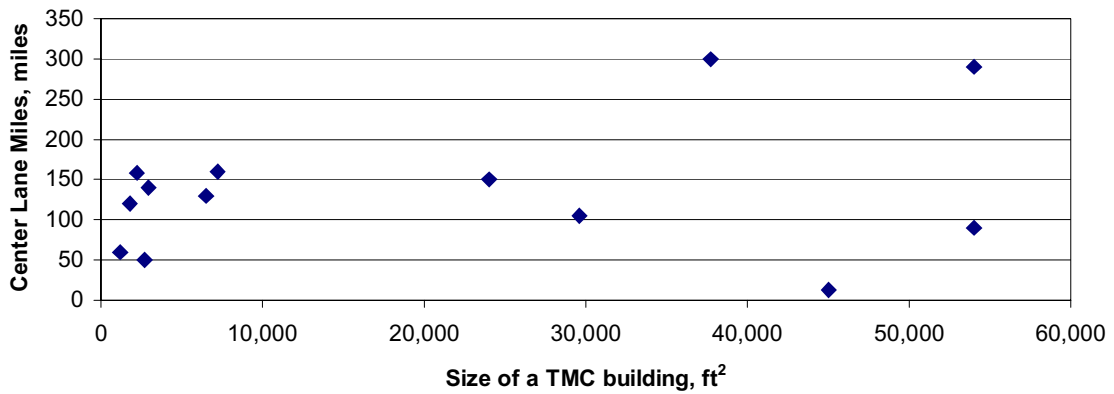


Figure 4. The Size of a TMC Building vs. Centerline Lane Miles

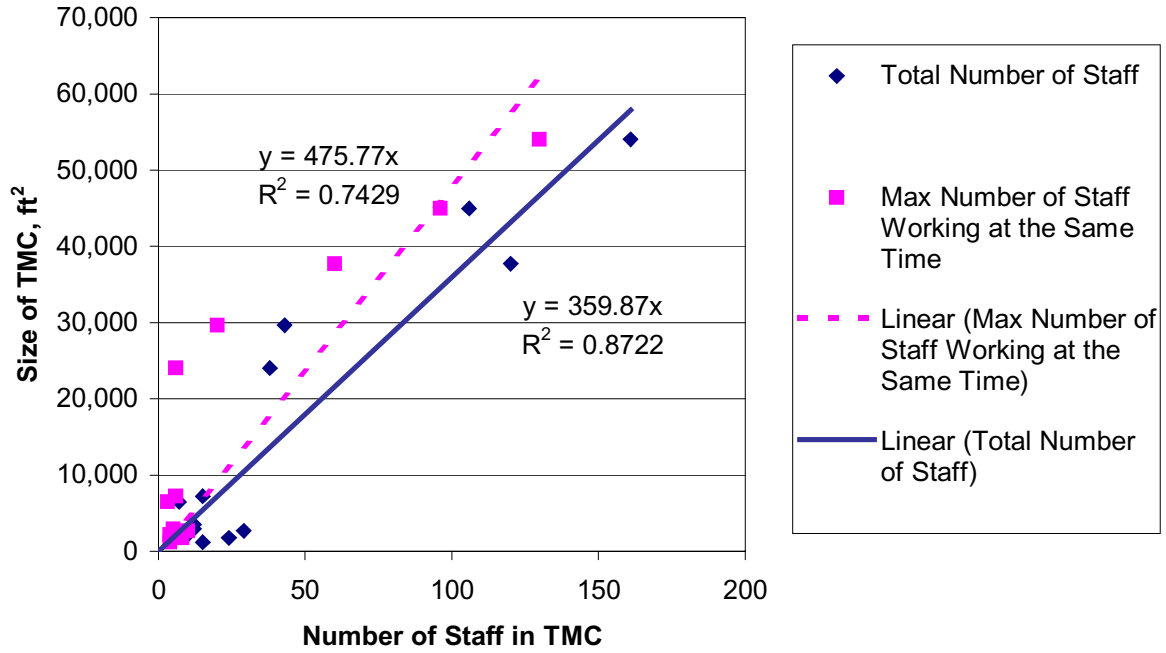


Figure 5. The Relationship between the Size of a TMC Building and Total Number /Max. Number of Staff Working at the Same Time

Table 5. Mean or Other Values for the Size of TMC Building per Staff

	Size per Total Number of Staff, sq. ft/person	Size per Max. Num. Of Staff Working At the Same Time, sq. ft/person
Mean	370	754
Standard Error	71	184
Standard Deviation	257	610
Sample Variance	66154	372534
Range	854	1942
Minimum	75	225
Maximum	929	2167

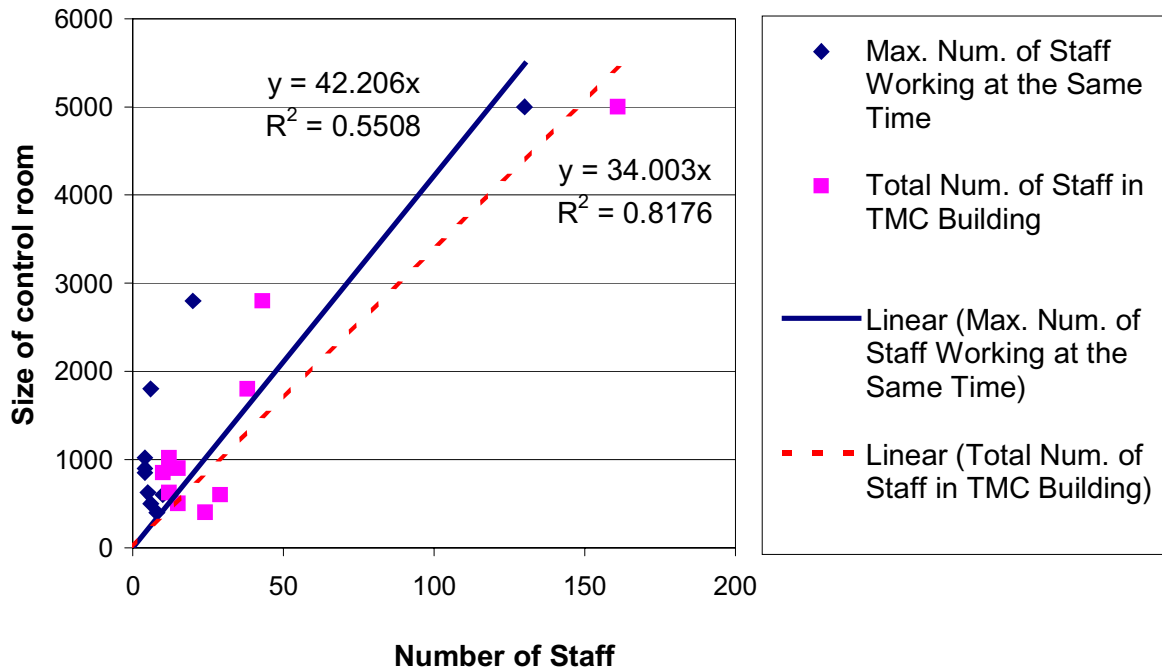


Figure 6. The Relationships between Size of Control Room and Number of Staff

Table 6. The Sizes of Surveyed Function Rooms of TMCs, Units: sq. ft.

Transportation Management Center	Control Room	Equipment Room	Conference Room	Offices	Kitchen Room	Rest Room
TranStar	5000			11231		
TransVISION	2800	1760	2000	7840		2232
Regional TOC/Rochester	2700	1687	650	600		
MITSC	2400					
Transp. Infor. Center	1800	1000	4160	3200		
NITTEC	1020	400	450	762	14	
Bridgeport Operation	900	100	300			
WSDOT Olympic Region	850	450		600		164
INFORM	625					
Capital Region / Albany	600	200	135	575	100	
Smart Traffic Center	500	200	400	500	100	100
NJDOT Region North	400	300	150	600		300

Table 7. The Ratio of Some Function Rooms to the Total Size of TMC Building

	Control Room	Offices	Conference Room	Equipment Room	Rest Room	Kitchen Room
Mean	23%	19%	10%	9%	8%	0.5%
Minimum	6%	1%	1%	3%	1%	0%
Maximum	75%	33%	25%	20%	17%	4%

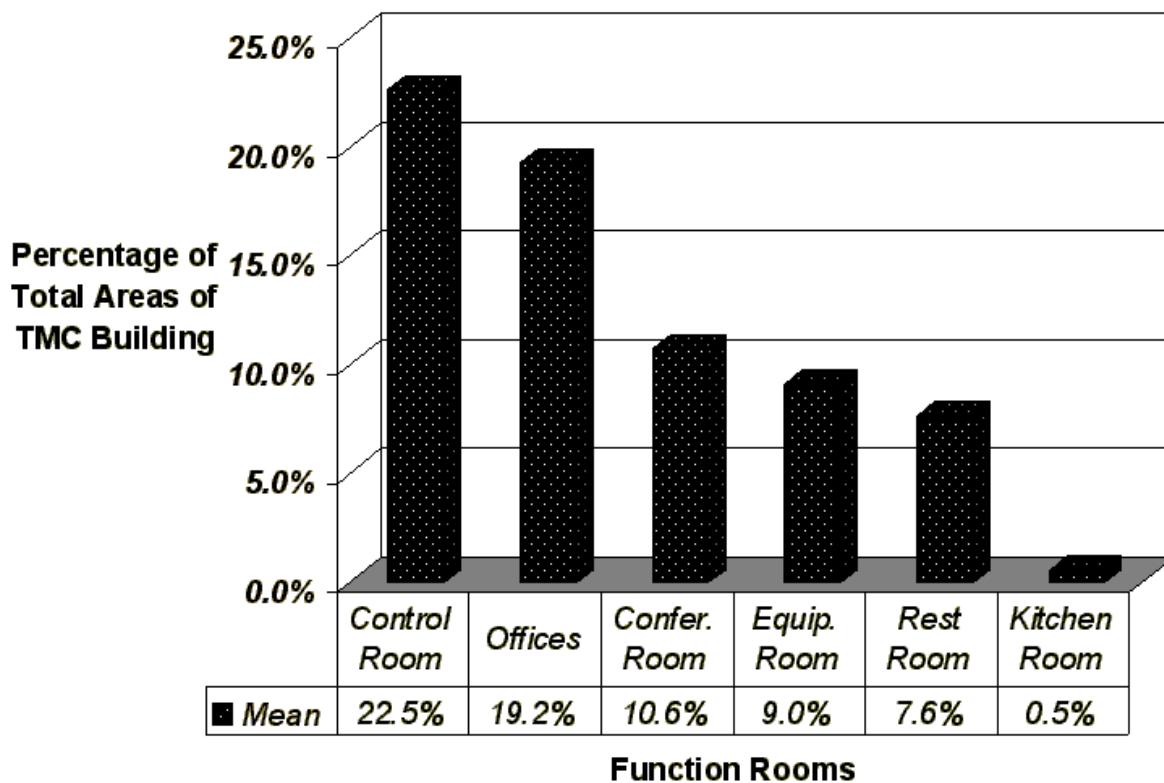


Figure 7. Arrangement of Function Rooms in Terms of Total Area of Building

Lessons Learned

There are several lessons learned from the responses of the survey. These lessons are important to designing a new freeway TMC building. Specific lessons learned in the following areas are discussed below:

- Original architecture design did not meet the proper function needs of TMCs;
- Future expansion capability of TMC building; and
- Security considerations.

Original Architecture Design Did Not Meet the Proper Function Needs of TMCs

The unique/specific HVAC requirements of one surveyed TMC were not considered in the original design. The needs of the TMC, which was thought to be an office space, were not understood in the original design. They had to correct those things after moving in.

One center manager wanted to have a briefing room next to control room and to add more offices with access to the control room. If she had a chance to redesign, she would design a larger computer room, more offices around perimeter of the control room, different console furniture layout, and better area for transient agencies in the control room.

One center manager said that the control room and the equipment room were too small. More office space should be added for plans and CADD equipment and put windows in the control center so that operators could look out to the adjacent interstate and get a feel for traffic and weather.

One center manager said that more floor space for the maintenance shop would be desirable. Further, it would be beneficial to have all the ITS functions on the same floor and they couldn't do that due to space limits.

One manager mentioned that the center was an interim center and there were a number of deficiencies too numerous to mention.

One center manager wanted a larger video wall with larger monitors.

One center manager wanted a larger equipment room for housing servers, cabinets, and communication equipments.

One center manager said that origin architecture design meets the functions. However, they always needed more office space, computer room space, maintenance space, storage space, and parking space.

One center manager wanted to add a training room.

One center manager said that the center had limited spaces with no expansion capabilities, and needed more storage room. The center should also have showers.

Future Expansion Capability of TMC Buildings

Future expansion capability is an important issue because the benefits of TMCs are so obvious that once a center is built, more agencies or functions may want to be added to the TMC. One center manager said that they already needed more room although their center was only seven years old. Another center manager wanted to add 50 percent more space into the building. In TranStar, in Houston, TX, there were only 10 consoles and 4 operators at the beginning in the control room. However, they already have 27 consoles and more than 20 operators working in the control room now.

Security Considerations of TMCs

Most center managers said that they had good security systems. Some centers were shared with the State Patrol. Only one center manager said that they were improving the access control to ensure that security was met. One center manager said that they were not sure whether their security system could prevent terrorism or not.

GUIDELINES FOR DESIGNING A FREEWAY TMC BUILDING

The designing of a freeway TMC building has its unique requirements and needs many careful considerations among multiple influence factors. Based on the survey, lessons learned, and other freeway center knowledge from the literature, e.g., Freeway Management Handbook (22), the guidelines for designing a freeway TMC building were developed by the authors and are summarized in a guideline flow chart shown in Figure 8. The instruction and detailed steps of the guidelines are discussed in the following paragraphs.

Instruction for Using the Guidelines

These guidelines are intended to help architects and engineers, who want to design a freeway TMC building, and agencies planning to implement a freeway TMC, to successfully design a TMC building and keep from repeating some common mistakes.

Prior to the use of these guidelines, several issues should be addressed. Specifically, the need for implementing a freeway TMC has already been determined. Additionally, the capital funds, as well as the availability of operations and maintenance funds, must already be available. However, it may be likely that the preliminary design of the proposed TMC building based on these guidelines is used as a part of funding proposal.

Guideline Contents

The following steps were developed by the authors to guide a freeway TMC building design. Some of these steps or order of these steps may be changed based on individual center situations.

Step 1: Establish clear objectives for building a freeway TMC

A necessary first step in the design process is developing the objectives for building a freeway TMC. Short-term as well as long-term objectives should be established, as the needs of the TMC building may change as long-term transportation network conditions change.

Step 2: Define the agencies to work in the TMC building

The number of agencies and type of agencies are very important factors affecting the design of a TMC building. A new agency added to a TMC may need more consoles in the control room, a special room for the unique devices, or an isolated office to deal with internal issues. The most common agencies in a freeway building are State DOT, Police, and Governmental agencies. Each TMC should also consider its own metropolitan needs for agencies.

Step 3: Define the functions and prioritize the functions in the TMC

The functions are very important factors affecting the size of a TMC building. One agency may perform several functions, while one complex function may need the cooperation of several agencies. Based on the survey, the most commonly used functions of a TMC are traffic management; traveler information; emergency management; incident and special event management; law enforcement; maintenance and construction management. The TMC should also consider its own local special needs, such as a fleet control function. The purpose of prioritizing the functions is to identify those functions that need to be done before others.

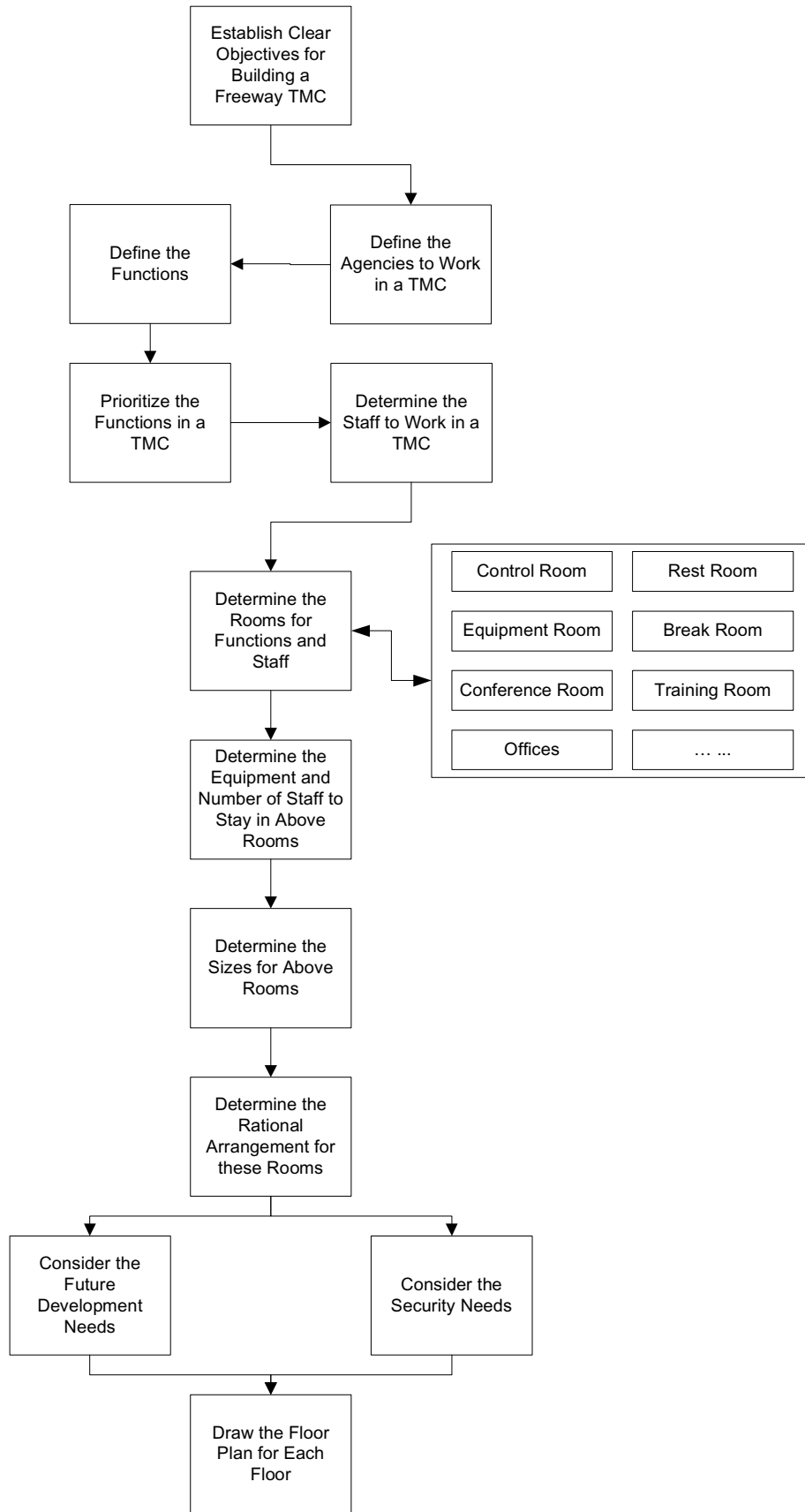


Figure 8. A Guideline Flow Chart for Designing a Freeway TMC Building

Step 4: Determine the staff to work in the TMC building

Determine who will work in the TMC building. The staff, such as operators, supervisors, police officers, maintenance staff, and repairpersons, is the most important part of the TMC. Staff's need should be put in priority order.

Step 5: Determine the rooms for functions and staff

In order to successfully provide the functions of the TMC, certain rooms are basic to a TMC building, such as control room (sometimes called communication room); and equipment rooms used for computers, communication devices, cooling and heating devices, maintenance, and repair equipments. Other rooms may be needed for staff, such as offices, conference room, break rooms, rest rooms, training room, etc.

Step 6: Determine the equipment and number of staff in each of above rooms

In order to implement a TMC, the equipment in a TMC needs to be determined. In a typical freeway TMC, the most common equipments are computer processing and storage equipments, communication equipments, and information display devices. The next step is to determine what equipments will be installed in each room. For example, for a control room, one needs to determine what type of workstation, console, monitor, and video wall will be used in the control room. The type and number of workstation, console, monitor, and other device will affect the size of the control room. The number of CCTVs for a video wall affects the size of the video wall. Also, the number of staff staying in each of these rooms needs to be determined. For example, for a conference room, one needs to determine the maximum number of staff that will be at a meeting. More people will need more room to work properly.

Step 7: Determine the sizes for above rooms and the building

After determining the equipment and the number of staff in a function room, the size of the room should be determined accordingly. The space of the control room should be based on the number and size of consoles; the maximum number of staff working at the control room at the same time; and other devices, such as printers, cabinets, etc.

Based on our survey results, typically, the size of a TMC building is directly related to the total number of staff and the maximum number of staff working at the same time in the TMC building shown in Figure 5. The more the staff working in a TMC, the bigger the size of the TMC building. From the survey of the current state-of-the-practice of the United States, Table 5, the average number of spaces per person in terms of total number of staff are 370 square feet per person, and the average number in terms of maximum number of staff working at the same time are 754 square feet per person. One can use these numbers for the preliminary design of a TMC building. For example, if the total number of staff working the TMC building is predicted as fifty, the preliminary size of the TMC will be 18,500 square feet. The minimum number of space per person and the maximum number of space per person in Table 5 are not recommended for design because the minimum number may be too small and the maximum number may not be necessary to perform the functions.

Figure 6 shows the simple linear relationship between the number of staff and the size of the control room of a TMC building. Based on Figure 6, if the total number of staff in the TMC building is assumed as 40, then the size of control room will be 1,360 square feet. And if the maximum number of staff working at the same time in the TMC building is assumed as 30, the size of control room will be 1260 square feet.

Another useful piece of information for the preliminary design of a TMC building is shown in Table 7 obtained from the survey of this research. Based on Table 7, one can estimate the sizes of each type of function room once the total size of a TMC building is determined. For example, if the size of the

building is 5000 square feet, the size of control room can be preliminarily designed as 1150 square feet based on that the size of control room is 23 percent of total size of building.

Step 8: Make a rational arrangement for the room

In order to better service TMC functions, some rooms should be arranged together, such as at least one conference room may be set up near the control room. Also, the rooms for the same function may be set together. For example, in TranStar, Houston, TX, one conference room is set right next to the control room. People in the conference room can easily see the activity in the control room and view the large video wall displays. This is convenient for the TMC to deal with some special situations because people can discuss the problem while they monitor the most updated information from the control room.

Step 9: Consider future development needs

Future expansion capability of a TMC building is very important for realizing agency long-term goals. The benefits of a TMC are so obvious that once it is built, more agencies or functions will want to be added to the TMC. In TranStar, in Houston, TX, there were only ten consoles and four operators at the beginning in the control room. However, They already have 27 consoles and more than 20 operators working in the control room now. One center manager said that they already needed more room although their center was only seven years old.

Step 10: Consider security needs for the building

The TMC building is one of the most important infrastructures of the nation. If a TMC building were destroyed, many ITS functions related to the TMC building would not work anymore and the consequent costs would be significant. Therefore, it is important to have a good security system. The most commonly used security systems are multi-layer access control, security guard, and police officers. Collocating the police officers into the TMC building can also improve homeland security. If a terrorism event happens, the police collocated in the TMC could help to manage the emergent situation.

Step 11: Draw the draft floor plan for each floor and then finalize it

After the above steps, the final step is to draw the draft plan for each floor and further check the fitness of the building design. The most important and effective way to design the TMC building is drawing draft floor plans on paper. One can identify many problems from the draft plans. For example, control room is not big enough to hold all the devices; some spaces are wasted; or the layout needs to be improved; etc. In addition, floor plans should be done using CADD for the purpose of saving time to revise. Finally, the design of the TMC building can be completed. As an example, Figure 9 illustrates the TMC building floor plan for Palm Beach ITMS Transportation Management Office.

COMMENTS FROM GUIDELINE REVIEWERS

Three TMC managers and one traffic engineer gave their comments for the guidelines on designing a freeway TMC building. In summary, the main points are listed as follows:

- The guidelines are clear and understandable;
- The guidelines are useful. It provides a good place to start, especially, with the numerical relationship provided; and
- The guidelines may include a listing of centers and their contact information. In addition, more sample floor plans may be added.

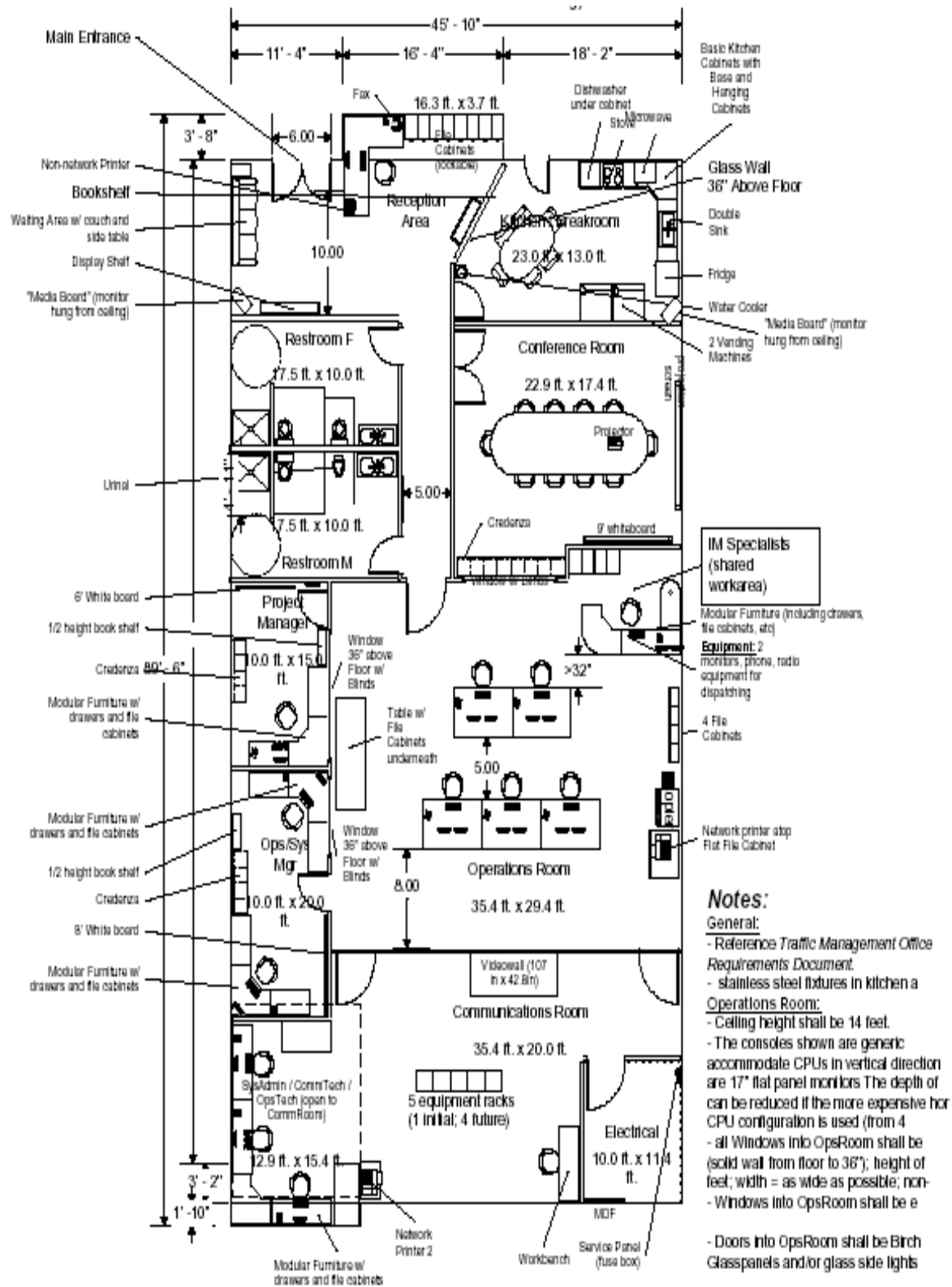


Figure 9. Conceptual Floor Plan of Palm Beach TMO (PB Farradyne Inc., April 2002)

CONCLUSIONS

The guidelines for designing a freeway TMC building were developed based on the responses of the managers or professional engineers from more than fifteen transportation management centers in States. The successful experiences and lessons learned were summarized and the relationships, such as the TMC size versus the number of staff in the TMC building, could be used as preliminary design figures for a new TMC building. These guidelines tried to provide useful information to keep the new planned or planning freeway TMCs from making the similar or unnecessary mistakes.

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APPENDIX A – SURVEY QUESTIONNAIRE



SURVEY QUESTIONNAIRE

Name: _____

Name of TMC: _____

Position: _____

Organization: _____

My name is DingXin Cheng. I am a graduate student at Texas A&M University and Texas Transportation Institute (TTI). I currently work on a research project related to developing guidelines for designing a freeway type TMC building for the 2002 Mentors Program. The final paper on this project will be collected in a compendium - Papers on Advanced Surface Transportation Systems, 2002. The following survey may take 10-20mins depending on the way the questions answered. Please return the survey by email (d-cheng@ttimail.tamu.edu) or fax (979-845-6254, attention: Ding Xin Cheng) no later than June 26, 2002. A copy of the compendium can be obtained for free if you request.

- How many agencies work in your TMC? _____. Check the agencies that you have in your TMC and fill out the blanks.

DOT	Police	Fire	Government	Media			

- What are the functions that exist in your Transportation Management Center (TMC)? Please check the functions that your TMC has in the following table and fill out the functions that are not shown.

1	2	3	4	5	6
Traffic Operation Management	Emergency Management	Toll Administration	Traveler Information	Commercial Vehicle Administration	Transit Management

7	8	9	10	11	12
Emissions Management	Maintenance and Construction Management	Fleet and Freight Management	Archived Data Management		

- How many centerline lane miles of freeway are covered by your TMC?
- How many staff are in your TMC? What is the estimated maximum number of staff working at the same time? What is the estimated maximum number of operators working at the same time? Could you send me a staffing chart if it is available?
- What is your operation hours? 24/7 or 16/5.
- What is the size of your TMC (how many square feet)?
- Could you send me a copy of the floor plan of your TMC so that I can measure areas of each room by myself? Otherwise, please check the rooms that you have in your TMC in the following table and add more if not mentioned in the table? How big are they (Sq. ft)?

	Control Room	Equipment Room	Conference Room	Offices	Briefing Room
Yes/No	Yes	Yes	Yes	Yes	
Sizes (ft ²)					
	Training Room	Bed Room	Dining Room	Rest Room	
Yes/No					
Sizes (ft ²)					

- Does the origin architecture design (i.e., arrangement of rooms) meet the proper function needs of you TMC? If not, what is the problem?
- Do you think that your TMC has a good security system to prevent terrorism?
- Do you think that your TMC thought about the future development issue from very beginning?
- How would change the design of your TMC building if you had a chance to redo your TMC?

12. Do you want a copy of the compendium – Papers on Advanced Surface Transportation Systems, 2002? Yes / No. If the answer is yes, please provide your mailing address.
13. Could I send you the draft guidelines to you for your opinion? Yes / No.

Thank you very much for filling out the survey!

APPENDIX B – SURVEY ON GUIDELINES

Name: _____

Name of TMC: _____

Position: _____

Organization: _____

Phone: _____

Email: _____

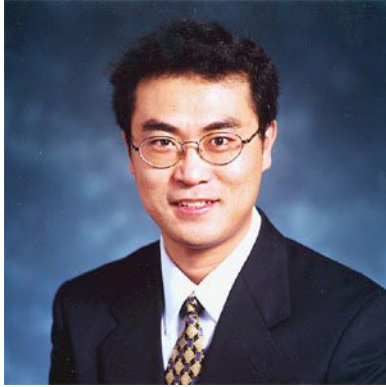
My name is DingXin Cheng. I am a graduate student at Texas A&M University and Texas Transportation Institute (TTI). My research topic is Developing Guidelines for Designing a Freeway TMC Building. Draft guidelines have been developed based on a survey of the current state-of-the-practice on TMC buildings. In order to improve the guidelines, I need the TMC experts like you to help me to review the guidelines. Therefore, I request your help.

The following survey may take 20-30 minutes depending on the way the questions are answered. Please return the survey by email (d-cheng@ttimail.tamu.edu) or fax (979-845-6254, attention: Ding Xin Cheng) no later than August 1, 2002.

Please review the enclosed guidelines first and then answer the following questions:

1. Do you think that the guidelines are clear and understandable? If not, which parts need to be improved? How should these parts be improved?
2. Do you think that the guidelines are useful for the engineers and architects who will design a TMC building? If not, which parts need to be improved? How should these parts be improved?
3. Are there other changes that you would suggest to improve the guidelines?

Note: The attached guidelines used for the survey are the same with the paper. Therefore, the guidelines are not repeated here.

DINGXIN CHENG

Ding received his Bachelor of Science degree in Civil Engineering at the Northeastern University of China in August 1991. During the four years of undergraduate study, he earned a lot of scholarships due to his excellent performances on both academic and extracurricular activities. After his graduation, he worked as an engineer for the China JingYe Construction Engineering Contract Company and also did research for the Central Research Institute of Building and Construction in MMI, Beijing, China. He attended the design and construction of the first patented extractable anchored tie-back retaining wall for the Bank of China in 1997.

He came to the United States in August 1998 and finished his Master of Science degree in Civil Engineering at the University of Toledo in August 1999. In Toledo, he worked as a graduate research assistant and developed a knowledge-based database system for the constitutive properties of soil using Visual Basic and MS Access.

Ding is currently pursuing his Ph.D. degree in Civil Engineering of the Texas A&M University. At Texas A&M, he worked as a teaching assistant for his first semester and then employed as a Graduate Assistant Research by the Texas Transportation Institute. He already published several papers during his Ph.D. study. He is now an associate member of ITE and ASCE. His major areas of interest include traffic operation, planning, ITS, and roadway design.

**TRAFFIC MANAGEMENT CENTERS: WHAT ARE THE BENEFITS TO
POLICE CO-LOCATION AND THE FUTURE IMPLICATIONS FOR
HOMELAND SECURITY?**

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SUMMARY

Traffic management centers (TMCs) are becoming an increasingly popular way for cities around the United States to manage traffic on the roadways. With more TMCs being built every year, it becomes important to take a look at different interagency coordination and co-location agreements in an attempt to determine the benefits to coordination and co-location. More specifically, in this project the relationship between the TMC and the police department was looked at in order to determine the benefits to police co-location at the TMC or alternatively, if there were any benefits to the police being located elsewhere.

A literature review was conducted to provide an overview of existing coordination and co-location agreements at TMCs. Surveys were sent to various TMCs and the police agencies that work with the TMCs in an effort to determine the benefits to police co-location at the TMC. Based on the literature review and the survey results, co-location may result in the following benefits:

- Improved incident detection, response, and clearance times;
- Improved understanding, trust, respect, and communication among agencies;
- Allow for better on-site management of incidents;
- Allow for improved sensitivities to each other's organizational objectives and responsibilities;
- Improved coordination to the actual response to scenes and the monitoring of impacts of incidents;
- Shared operation of the TMC to allow for 24-hour operation.

In addition, the future implications for homeland security are discussed in this paper. Primarily, the objectives were to determine the role of the TMC in case of another homeland security attack and to determine what coordination and co-location agreements need to be in place to be adequately prepared for another attack. Through a literature review and survey results, the TMC may perform the following functions during a homeland security attack:

- Surveillance;
- Traffic management; and
- Providing information to the police and the public.

The following coordination agreements need to be in place to be adequately prepared for another attack:

- Make a plan;
- Practice the plan;
- Establish a person-in-charge
- Establish a command center; and
- Communicate with each other and the public.

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INTRODUCTION

The increase in traffic congestion has prompted engineers to investigate ways to accommodate traffic. Along with expanding the existing roadway system, transportation agencies are forced to manage the traffic on the existing system in an attempt to battle congestion. The traffic or transportation management center (TMC) has become the central point for operating and monitoring traffic management systems. The TMC is the “nerve” center for the collection and dissemination of transportation information (1). The information collected at the center is used to initiate strategies to effect changes in the operation of the system when congestion occurs. In addition to managing congestion, the TMC plays a critical role in incident management. The technology at the TMC allows for the quick detection and immediate response to incidents. The quick detection, response, and clearing of incidents helps to alleviate the congestion caused by the incident and reduce the risk of secondary incidents. The TMC is also the focal point to communicate transportation related information to the motoring public and the media (2).

Many different agencies are responsible for the roadways in a location. Most often people’s travel patterns require the use of different transportation modes, crossing agency lines, and crossing jurisdictional boundaries. Therefore, many different agencies are involved in the transportation operations of a city, county, or state. For that reason, transportation problems can rarely be solved by one agency alone. It is common practice in the United States for many different transportation agencies to reside in a TMC together. Besides the transportation agencies, such as the state department of transportation and the county and city traffic transportation departments, other public service agencies are often involved in transportation incidents such as the police department, fire department, and the EMS. Therefore, when a transportation incident occurs, multiple agencies are involved with different roles and responsibilities. It is also common for the agencies to have different priorities and motivations. This presents a unique challenge for the agencies at the TMC to coordinate and cooperate in the midst of an incident.

Although many public service agencies are involved when an incident occurs, it is important to have cooperation between the TMC and the police agency responsible for the roadways in the area. The police department is most often the agency to be contacted when an incident occurs. When this occurs, the police department will contact the TMC if they need assistance in clearing the incident. The TMC is capable of verifying the incident by use of closed circuit television cameras (CCTVs), and aiding in the response and clearance of the incident. However when there is not a cooperation and communication agreement between the TMC and the police agency there can be a time lapse between the police learning of the incident and then notifying the TMC. This time lapse whether it is just seconds or minutes allows for an increase in congestion to occur on the roadway and therefore increases the risk of secondary collisions. Because of this need for cooperation and quick correspondence between the agencies, many police agencies have begun to co-locate at the TMC.

As inter-agency coordination has become more popular at TMCs across the country, multi-agency co-location is slowing following. Research is needed to determine the “state-of-the-practice” on inter-agency co-location agencies. In particular, the relationship between the traffic engineers and the police has become a debated topic. Traffic engineers and police historically have different priorities when it comes to managing a traffic incident. The traffic engineer’s primary objective is to restore the flow of traffic as soon as possible to lower congestion levels and to reduce the risk of secondary crashes. At the same time, the police agency may want to lower travel speeds at the scene and keep lanes closed for an extended period of time for a crash scene investigation. Despite these conflicting objectives, traffic engineers and the police are beginning to co-locate at TMCs in the shared goal of improving incident management. As more TMCs are being constructed across the country, it is necessary to determine what the benefits are to police co-location at the TMC, or alternatively, are there benefits to the police being located elsewhere?

In the months following September 11th, much focus has been placed on the state of security on our nation’s roadways, and on improving the existing level of security. The role of the TMC during a

homeland security threat or attack is being closely examined. Coordination between the traffic engineers and the police will become extremely necessary and unavoidable during a homeland security attack. Therefore, recommendations are needed to outline what coordination and co-location agreements are needed between the TMC and the police to prepare for a homeland security threat or attack.

PURPOSE AND RESEARCH OBJECTIVES

The purpose of this research is to explore what interagency cooperation and co-location agreements currently exist at different TMCs and to determine, in particular, what the benefits are to police co-location at the TMC, and furthermore, what the implications are for homeland security. Existing interagency cooperation and co-location agreements learned from literature review and a survey of various TMCs will serve as a basis for this research. Specifically, the objectives of this research effort were to:

1. Provide an overview of interagency co-location and cooperation agreements at various TMCs;
2. Investigate the benefits of the police co-locating at the TMC;
3. Investigate the benefits of the police being located at an alternate location; and
4. Discuss future implications for homeland security.

STUDY APPROACH

This research project was divided into two major parts. In the first part, the focus is on the benefits to police co-location at the TMC. First, a literature review was conducting to provide an overview of current interagency co-location and cooperation agreements. Next, a survey was sent to various TMCs and police agencies across the country. The purpose of the survey was to gain insight into the relationships between the traffic engineers and the TMC and the police agencies that work with them. The survey was designed to determine what the benefits are to police co-location at the TMC and alternatively, what are the benefits to the police being located elsewhere. In the second part of this research project, the future implications for homeland security are discussed. A literature review was conducted to determine what steps are currently being taken to prepare the county for another attack. The survey discussed previously which was sent to the TMCs and the police agencies also included questions regarding homeland security. The goal of the survey questions was to gain the TMC and police agency personnel's perspective on what the role of the TMC should be during an attack. In addition, the research wanted to determine police and TMC co-location and cooperation agreements need to be in place to be prepared for a homeland security attack.

LITERATURE REVIEW

Traffic Management Centers (TMCs)

The concept of traffic management in the United States in the 1960s and 1970s began as the traffic volumes began to rise rapidly. At the same time, the construction of new roadways was slowing down which forced agencies to develop new and innovative ways to manage the congestion on the existing system without expanding the capacity. The TMC has become the focal point for operating and monitoring the traffic management systems.

The TMC is a facility that brings together the management and coordination of all the transportation resources and technology. The TMC serves many different roles and functions depending on the needs of the community that it serves. Some of the major functions of the TMC are roadway management,

incident management, fleet management, traffic signal control, system control and data, and information dissemination (3).

Roadway Management

Roadway management consists of the monitoring of recurrent traffic on the system. Some of the functions of roadway management are to balance flow between alternative routes, determining relative travel times for alternative routes, and ramp metering. The control of high occupancy vehicle (HOV) facilities can also be included in this category (3).

Incident Management

Incident management is one of the primary concerns of every TMC. Incident management is the detection, verification, response, and clearance of an incident on the roadway. An incident can vary from a stalled vehicle to a multi-vehicle crash. Some common incident management procedures that are utilized by TMCs include motorist assistance patrols, efficient procedures to detect, verify, respond to, and clear incidents, and to provide effective traffic control in the midst of an incident. All of the procedures are used to reduce the amount of time that lanes are closed and to create alternative routes to reduce congestion and the risk of secondary crashes (3).

Fleet Management

Fleet management is a concept that outdates TMCs. Transit agencies have been managing their fleets from centers similar to TMCs for many years. The most common function of fleet management is vehicle location monitoring to determine schedule observance and vehicle headways (3). Transit agencies have recently been cooperating with TMCs to share this information.

Traffic Signal Control

Traffic signal control is the process of monitoring the flow on signalized roadways and responding to the real-time information that is collected. The signal timing plans can be changed instantaneously to reflect the existing conditions on the roadway. Typical changes would include adjusting the cycle lengths or splits or else the operation could be changed to flash mode, actuated operation, or fixed-time operation. The TMC can also detect any problems with signals in the network and send out the appropriate maintenance or traffic control personnel (3).

Information Dissemination

Information dissemination is one of the main priorities of every TMC. There are many different ways to share information with the motoring public and the media. The information can be shared by displaying messages on variable message signs or by using highway advisory radios. Alternatively, traveler information can be shared via the media, press, Internet, telephone, or fax. Information sharing will typically occur during and after an incident, and prior to and throughout a special event.

Benefits Provided by the TMC

In the previous section, the functions that are performed by TMCs were discussed. Some of the benefits of TMCs include the following (3):

- Faster incident response and reduction in incident rates;
- Increased safety through the reduction in incident rates and chances of secondary incidents;
- Reduction in non-recurrent congestion; and
- Enhanced communication in all aspects in transportation management.

There have been little data to quantify the exact benefits achieved by the TMCs. In a study conducted by the Minnesota Department of Transportation, it was reported that there was a decrease in accident rates by twenty-five percent, twenty minute reduction in response time, thirty-five percent increase in average traffic speeds during peak hours, and a twenty-two percent increase in the capacity of the freeways, after the implementation of the TMC (3).

Inter-Agency Coordination

Inter-agency coordination is necessary to achieve the full benefits of the TMC. A person's daily travel patterns require crossing jurisdictional boundaries therefore it is necessary to have cooperation and coordination between the agencies. This can be accomplished by improving the working relationships among all of the agencies that deal with incidents such as the transportation agency, law enforcement, fire and rescue, and maintenance personnel from multiple jurisdictions.

Some features of inter-agency coordination may include the following (4):

- Agreement of common goals prior to the incident occurrence;
- Adoption of cooperative policies;
- Joint inter-agency training opportunities;
- Development of inter-agency incident management handbooks;
- Resource sharing among participating agencies;
- Co-location of core incident management personnel;
- Frequency interaction among partner agencies;
- Prior joint planning for on-scene staging and traffic management; and
- Periodic incident management program review and regular evaluation.

Some benefits of inter-agency coordination may include the following (4):

- Promote better understanding, trust, respect, and communication among agencies;
- Improved incident detection, response, and clearance times;
- Promote the sharing of resources among agencies;
- Allow for better on-site management of incidents;
- Allow for improved sensitivities to each other's organizational needs and extended faith in each other's abilities;
- Allow agencies to gauge expectations;
- Allow for improved safety resulting from more efficient response/incident clearance processes;
- Allow for improved public awareness through better communication and real-time updates about incidents to the public;
- Consolidated dissemination of information;
- Promote unified command structure; and
- Enhance the cooperative efforts of field responses and activities.

As the relationships among the agencies grow, the activities of the TMC will improve and the full benefits of the TMC will begin to be realized.

Current Inter-agency Coordination Activities

The practices of TMCs have been well documented by the FHWA as a tool to educate the public sector about particular intelligent transportation system (ITS) technology. ITS America and the Institute of Transportation Engineers (ITE) have also published many reports regarding the current practices at various TMCs. The focus of this literature review is to provide a background of the TMC, and

interagency cooperation and co-location agreements of different TMCs. The following TMCs will be discussed in this literature review.

- Georgia Navigator
- Houston TranStar
- Hudson Valley TMC
- Mn/DOT TMC

Georgia Navigator

The Georgia Navigator system was originally developed to address incident management, congestion management, and motorist assistance concerns for the 1996 Olympic Games in Atlanta (5). The primary objective of the system was to provide accurate and timely information for the travelers on the Georgia roads. This system is one of the most advanced in the country. The TMC utilizes a fiber optic network, the public phone system, three radio systems, and an aerial surveillance microwave link (5).

The Georgia Department of Transportation (GDOT) was responsible for the creation of the Navigator system. Although there are interagency cooperation agreements among many agencies in this area, the GDOT is the only agency located at the TMC. The other operational partners that are not co-located at the TMC include the City of Atlanta, Clayton County, Cobb County, DeKalb County, Fulton County, Gwinnett County, Metro Atlanta Rapid Transit Agency (MARTA), and the Georgia Emergency Management Agency (6).

In everyday activities at the TMC, the operators communicate verbally across consoles with one another. They communicate by radio with the Highway Emergency Response Operators, and by phone with the fire department, emergency medical services, and law enforcement. Traffic control centers are set-up at the operational partners that are not co-located at the TMC. These “satellite” TMCs have video and computer access and have full access to all traffic information contained within the Navigator computer system. The TMC also receives faxes from the local jurisdictions regarding construction (5).

Transit is a strong operational partner with the TMC. MARTA also houses one of the “satellite” TMCs in its bus control room. MARTA is capable of entering and modifying incident, congestion, and other information into the system just as if they were located in the same room at the TMC (5).

Houston TranStar

Houston TranStar consists of a partnership of four different agencies, the Texas Department of Transportation (TxDOT), the City of Houston, Harris County, and Houston Metro. These agencies recognize that most travelers use varying modes and cross jurisdictional boundaries on a daily basis. Therefore they came together to assist the transportation community by collecting and processing transportation information, distributing that information to transportation and emergency management staff, providing information to travelers, managing incidents, and providing assistance to disabled vehicles and area-wide emergencies (7).

The center is staffed by city, county, transit, and state personnel, who cooperate on all aspects of transportation management (7). In everyday activity at the center, incidents are detected by visual monitoring of congestion levels using the area map, through cellular 911 calls received by Harris County, reports from law enforcement officers and the motorist assistance patrol, and from monitoring of the CCTVs receiving real-time data from the roadways.

The transit system, Houston METRO, is also active at the TMC. METROs personnel perform bus fleet dispatch and management from within the TranStar control room. METRO also performs project

management, special events planning, high occupancy vehicle (HOV) operation, and enforcement functions from within TranStar (7).

The coordination between the agencies is in person or by telephone. Although each agency has its own responsibilities, all agencies share access to variable message signs and CCTVs. Each agency that has personnel in the field communicates with them by two-way radio.

Recently, interviews of constituents were conducted by the Texas Transportation Institute regarding the performance of Houston TranStar (8). Some of the strengths of TranStar as seen by the constituents included the good working relationships and coordination among the transportation agencies, and the benefits of the transportation and emergency management operations co-located together at one site.

Hudson Valley Traffic Management Center

The function of the Hudson Valley TMC is to improve the operation of the highway system through teamwork and technology, thereby improving the mobility of travelers and goods in the Hudson Valley (9). The Hudson Valley TMC relies on a partnership between the NYSDOT, the New York State Thruway Authority, and the New York State Police. The TMC will be the central point for the collection and dissemination of transportation information, management of roadway and transit conditions, management of congestion, and roadway event and incident related traffic. Hudson Valley TMC personnel believe that improved transportation management can only be achieved through the coordinated efforts of a variety of agencies (9). The ITS programs instigated at the Hudson Valley TMC as well as other New York TMCs place a strong emphasis on providing leadership in establishing inter-agency transportation partnerships on a local, regional, and national basis (9).

Mn/DOT TMC

The Mn/DOT TMC was constructed in 1972. The TMC currently receives data from seventy percent of the freeways in the Twin Cities Metropolitan Area. The personnel that are located at the TMC include the Mn/DOT Metro Division, which consists of the traffic engineering staff that operate the traffic management system, as well as the electrical maintenance staff that maintains the equipment, and a Minneapolis public radio station broadcaster (10). The TMC has many other operational partners that are not co-located at the TMC. These agencies include the Minnesota State Patrol, highway maintenance dispatch, Highway Helpers, Mn/DOT Metro Division traffic signal operations, Metro Transit, city and county traffic signal operations, emergency responders, and information service providers such as private sector radio and television traffic reporters (10). The TMC currently communicates with the State Patrol and other emergency responders via radio, computer, telephone, and monthly Incident Management Committee meetings.

SURVEY RESULTS

There are many different levels of interagency coordination and co-location at TMCs across the country. One of the objectives of this paper was to investigate the benefits of police co-location at the TMC and alternatively to determine if there are any benefits to the police locating elsewhere. To accomplish this objective, a survey was sent to various TMC personnel around the country. The survey was sent to TMCs of various size and age. The author also attempted to survey TMCs with different levels of co-location and cooperation with the police. The survey consisted of sixteen short answer questions. The purpose of the survey was to gain information on the following topics.

- Are there benefits to police co-location;
- What are the impacts on incident management;
- How are the working relationships between the traffic engineers and the police;

- Do the traffic engineers and the police and different priorities that could cause conflict;
- What is the decision-making process between the agencies; and
- Is there a conflict resolution protocol;
- Are there benefits to the police being located elsewhere.

A representative of the following TMCs responded to the survey.

- Capital Region TMC - Albany, New York
- Navigator – Atlanta, GA
- TranStar – Houston, TX
- Mn/DOT TMC – Minneapolis, MN
- Smart Traffic Center – Arlington, VA
- East Baton Rouge Parish/LA DOTD Advanced Traffic Management and Emergency Operations Center – East Baton Rouge, LA
- Traffic Operations Centers North and South – Newark, NJ
- Hudson Valley TMC – Poughkeepsie, NY

In addition, surveys were sent to the police agencies that work with the TMCs. The following police agencies responded to the survey. The survey was designed differently for the police agencies that are co-located with the police and the police agencies that are not co-located with the police. If the police are co-located at the TMC, then the goal of the survey was to determine the following.

- If the police are co-located at the TMC and if so, how many are located there;
- What brought on the co-location agreement and what were the goals of the arrangement;
- How is the working relationship between the police and the traffic engineers;
- Do the police and traffic engineers have different priorities which could cause conflict;
- Do the police realize the added value of having professional traffic engineering expertise as part of their protocol;

If the police are not currently co-located at the TMC, then the survey questions were designed to gain the following information.

- How do you currently contact the TMC if you need assistance;
- Are there any disadvantages in the exchange of information;
- Have there been time delays in getting the assistance;
- Do the police and traffic engineers have different priorities which could cause conflict;
- Do the police realize the added value of having professional traffic engineering expertise as part of their protocol;
- Would you like to see your agency be co-located at the TMC.

Representatives from the following police agencies responded to the survey.

- Minnesota State Patrol
- New State Police
- Houston Metro Police

TMCs With Police Co-Location

The information learned in the survey of the TMCs with police co-location is discussed in the following section. The information from the survey is summarized in Table 1.

Table 1. TMC Survey Responses

TMC	Is there an improvement incident detection?	Is there a good working relationship?	Do traffic engineers and police have different priorities that could cause conflict?	How is the decision-making process handled?	Is there an agreed upon dispute resolution protocol?	Additional benefits to police co-location?
Houston TranStar	Yes	Yes	Yes	Defined Management Structure	Defined Management Structure	Traffic engineers and police realize the impact of their actions on the other
Smart Traffic Center	No	Yes	No	Monthly incident management meetings	Incident Management Manual	None
East Baton Rouge	Yes	Yes	No	Regional Incident Management Plan	No	Overall improvements in managing incidents
Capital Region	Yes	Yes	Yes	Incident Command System	Police have the final say	Police operate center during off-hours and improved response to incidents
New Jersey	Yes	Yes	No	Collaboratively between the agencies	Police have the final say	Advanced the program to other State and local police

What Brought About the Co-Location?

The partnership between the New York State Police and the New York State Department of Transportation (NYSDOT) is one of the strongest examples of inter-agency coordination. The New York State Police and the NYSDOT currently have many partnerships agreements underway at TMCs across the state.

The New York State Police and the New York State Department of Transportation (NYSDOT) are currently co-located at the TMC in Albany and Hudson Valley. The set-up consists of the NYSDOT personnel co-located at a State police regional communications center. From 7AM-7PM there are two DOT employees at the center operating the ITS equipment. During the off-hours, the state police personnel operate the center (11). There has been a strong partnership between the State Police and the NYSDOT on several initiatives. When incident management came to the forefront in the mid 1990s, the NYSDOT funded a State Police Lieutenant to work within one of the NYSDOT regional headquarters to assist in improving incident management. This arrangement helped to open the door for co-location (11).

A Captain, a Sergeant, and two Troopers currently staff the interim Hudson Valley TMC in New York. Once the permanent facility is constructed, approximately thirty officers will be located there as well as a C-911 Dispatch point for the county. The police co-location at the TMC began three years ago when the New York State Department of Transportation (NYSDOT) recognized the benefit of co-location towards their goals in incident management. The officers are handpicked to work in the TMC based on their ability to work in such an environment. According to a New York State Captain who currently works in the TMC, the police definitely see the benefit of the value added by having professional traffic engineering expertise as part of their protocol (11).

Incident Detection

The results of the survey indicated that all of the TMCs that are co-located with the police found some benefits to this arrangement. The primary reason that TMCs co-locate with the police in the first place is to improve incident detection. At the Capital Region TMC in Albany, the best incident detection that is available is through 911 cellular telephone calls, which are received by the State Police that are located at the center. Therefore the TMC is immediately notified of an incident on the roadway. The DOT can immediately begin to handle the incident before or as the public safety personnel are receiving the initial dispatch to respond (12). The TMC in East Baton Rouge sees an overall improvement in incident management. Having the advanced traffic management system, Highway Patrols, and the 911-dispatch center located together helps to quickly detect and manage incidents (12). At Houston TranStar, incident detection has improved, but incident response is, “still a work in progress” (13). The Director of Houston TranStar notes that, “there are many institutional attitudes to change and an education process to continue” (13). At the TMCs in New Jersey, the police co-location has improved the relationship with the State Police dispatch centers and DOT has begun to use the State Police radio system.

Working Relationships

The survey also investigated the set-up of the police and traffic engineers at the TMC. The researcher wanted to know if the traffic engineers and the police worked side by side at the TMC and if there is a good working relationship. Of the TMCs that were co-located with the police that were surveyed, all but one indicated that the traffic engineers and the police work side by side in the control room. All of those surveyed stated that there is a good working relationship. At the TMC in New Jersey, the program has been in place for eight years and has worked so well that it has led to other police/DOT initiatives (14). At the TMC in Albany, “the agencies are on board with the program and the personnel working at the TMC from both agencies either accept the program or else enjoy the working relationship and cross agency benefits to co-location” (12). In Baton Rouge, the working relationship currently is good but a representative of the TMC noted that, “people make the relationship good, not the agency. In fact, if you

are not careful, agencies can oftentimes hurt or even destroy relationships (15)". Houston TranStar also stated this same concern. A representative of TranStar said that, "overall organizational working relationships ebb and tide as personnel rotate through the organization...a change in personality can make a huge difference in the way that the entire place operates (13)".

Priorities of Traffic Engineers and Police

Traffic engineers and police have conflicting priorities when dealing with a traffic incident. The traffic engineer's job is to keep travel lanes open or to reopen travel lanes as soon as possible after an incident. This is in hopes of reducing congestion and lowering the risk of secondary crashes. On the other hand, the police want to keep travel speeds lower at the scene or to keep travel lanes closed for an extended period of time for to investigate the crash.

The strong partnership between the New York State Police and NYSDOT has been able to successfully overcome these conflicts. The relationship between the traffic engineers and the police has allowed both agencies to understand each other's objectives and to reach a compromise. The traffic engineers understand that sometimes it is necessary to keep lanes closed for an extended period of time while the police also understand the risk of secondary crashes due to the lane closure (12). The experiences at Houston TranStar have shown that this is an education problem. The TMC and the police need to be educated and familiarized with each other's roles and responsibilities in order to improve coordination (13).

Multi-Agency Decision Making Process

Since the police and traffic engineers have differing priorities, the TMCs typically have a decision making process. At the TMC in Albany, the state and local agencies utilize the Incident Command System. The Incident Commander, who is a representative of the police, has control over the incident and works with all the involved agencies. The TMC has no direct authority over the management of incidents. A representative of the TMC noted that, "they are a support center providing "one stop shopping" for transportation information"(12). The Capital Region TMC has established two Traffic Incident Management task forces. This involves the local public safety and transportation officials to meet every few months and discuss major incidents and to pre-plan for scheduled events (12). This has resulted in the various "players" to establish friendships to help them work well together when an incident occurs.

At Houston TranStar, where multiple agencies interact daily, they have established a management structure. The structure consists of three levels and each level is comprised of representative from the four partnering agencies. The first level is the Executive Committee, which is responsible for setting policy and deciding upon fiscal matters. The second level is the Leadership Committee, which administers the agency staff assigned to the TMC. The third level is the Agency Managers Committee, which is made up of managers of the transportation and managers groups, and is responsible for overseeing the daily operations at the center (7). To handle the decision-making process in Baton Rouge, a regional incident management plan has been developed that documents the process for incidents. Typically for most major incidents, the East Baton Rouge Parish Fire Department is the first responder and manages the scene with assistance from the police (15).

Dispute Resolution Protocol

With many agencies working together, conflicts often occur, therefore, most TMCs have an agreed upon dispute resolution protocol available to best handle a conflict that occurs between agency representatives. In New Jersey, the police have the final say and disputes are resolved after the fact via a post incident critique procedure (14). At the TMC in Albany, when incidents occur on-scene, the incident commander, who is a representative of the police agency has the final word. Also as conflicts occur at the TMC, the State Police supervisor would have the final decision. However, a representative of the TMC noted that

in the three years they have been in operation, this has not been an issue. DOT and police personnel have always agreed upon a course of action (12). According to a New York State police officer most conflicts are avoided because each agency sticks to their own task. For instance, the police defer to the traffic engineers relative to the operation of the ITS equipment while the traffic engineers allow the police to make the necessary decisions regarding lane closures and detours (16).

Additional Benefits

Besides the improvements in incident detection, TMCs have noted some additional benefits to police co-location at the TMC. A representative of the TMC in Albany noted many additional benefits to the co-location agreement. The TMC is not a twenty-four hours a day and seven days a week operation yet. During the off-hours of the DOT personnel, the police utilize the CCTV cameras and activate the variable message signs for both roadwork and incidents. The DOT has placed a traffic management terminal at the State Police supervisor's workstation. The police have access to a variable message sign manual that provides pre-planned instructions to activate the variable message signs. In case of more serious incidents, the State Police page a traffic engineer for remote assistance (12). The TMC in Baton Rouge have seen tremendous improvements in dealing with other police or emergency service agencies. The co-location has also helped the police to understand the Statewide Incident Management Program and have been able to advance the program among other State Police and local police (15).

A New York State Police Captain also saw additional benefits of police co-location for the police force. He stated that many of the police personnel are cross trained and have developed valuable knowledge about traffic safety and engineering issues which they can pass along to their peers. This can ultimately change the culture of the police response to traffic incidents, including the training of quick clearance strategies, which have not previously been a concern (16).

The New York State Police also have improved coordination of the actual response to incidents and the monitoring of the actual response. The proof of this is found in the State Police radio transmissions on a daily basis. The State Police now routinely ask the TMC to "pan the camera" and give a report as to the best direction to approach as scene or to ask for additional information on the incident such as types of vehicles involved or the number of lanes blocked (16).

TMCs Without Police Co-Location

A survey was also sent to TMCs where the police are not present. The survey focused on the way that the traffic engineers communication with the police, the disadvantages incurred in information exchange, the working relationships, and the benefits of police not being co-located at the TMC. The results of the survey are summarized in this section.

Communication

Since the traffic engineers and the police are not co-located, different means of communication are needed when an incident occurs. At the TMC in Minneapolis, the traffic engineers and police communicate via radio, computer, and telephone and have monthly Incident Management Committee meetings. Likewise, at Navigator in Atlanta, the TMC and the police communicate by radio and phone and also have monthly meetings. Both agencies admit there are disadvantages to this arrangement. Navigator notes problem such as the failure to be notified of incidents and the lack of coordination of activities. Furthermore, at times there have been delays when police input is needed for a decision (6). Similar problems have occurred at the TMC in Minneapolis. The TMC says that when the traffic engineers are busy managing multiple incidents, the communication between the TMC and the police is less effective than it should be. Both agencies get focused on their individual objectives and forget about the big picture (10). The Minneapolis TMC also says that time delays have occurred when police input is

needed for a decision. An example of this is when the TMC needs the State Patrol approval for a custody towing.

Working Relationships

The TMCs located on Atlanta and Minneapolis note that there are good working relationships between the traffic engineers and the police. Both parties are familiar with each other through monthly incident management meetings.

Additional Help from the Police

From the survey presented to the TMCs with police co-location, it was found that in a couple of cases the police operated the TMC in off-hours. The survey sent to the TMCs without police co-location asked if this was possible at their TMC. The Minneapolis TMC responded that currently the State Patrol takes over control of the CCTV cameras. Also the Minnesota DOT Highway Maintenance takes over control of the variable message signs, however this is only in the case of serious incidents or roadwork and lane closures. Currently both of these agencies receive the video feed from the TMC as well as the congestion incident map (10).

Navigator says that the police could not completely run the TMC during off-hours but there are some functions that the police could do. The police could receive the calls of incidents, record them, and provide dispatch for the incident management response team. However it would be difficult for the police to dispatch maintenance for the entire Georgia DOT during the off-hours (6).

Benefits to Police Begin Located Elsewhere

By design the Georgia DOT is the only agency located at the TMC. Early on in the development of Navigator, the DOT determined that it wanted the system to be “re-usable” for all other urban areas in the state (9). Because of all the operational partners with Navigator, it seemed impossible to get all the agencies and personnel together in one room. Therefore, rooms were constructed so that were functionally and electronically connected to each other, even though many miles separate the rooms. This accomplishes nearly the same thing as being in the same room, but without the confusion and with the added value of the agency having full ownership of the activities. A representative of Navigator stated that to co-locate all the agencies at the TMC would be overwhelming. However, Navigator has invited the Georgia State Patrol to co-locate at TMC and would like to see this happen in the future (9).

The TMC in Minneapolis does not see any benefits to the police not being located at the TMC. In fact, the Minnesota DOT is building a new traffic TMC that will house the current TMC staff, State Patrol dispatch, and the Highway Maintenance dispatch. It is scheduled to open in the fall of 2002 (10).

FINDINGS AND RECOMMENDATIONS

Findings

The following findings are based upon the results of the survey questionnaire sent to the TMCs and the police agencies and the literature review discussed in the previous sections.

Co-location of the TMC and the police may result in the following benefits:

1. Improved incident detection, response, and clearance times;
2. Improved understanding, trust, respect, and communication among agencies;
3. Allow for better on-site management of incidents;

4. Allow for improved sensitivities to each other's organizational objectives and responsibilities;
5. Improved coordination to the actual response to scenes and the monitoring of impacts of incidents;
6. Shared operation of the TMC to allow for 24-hour operation.

There are alternative arrangements than police and TMC co-location that may be beneficial. There are TMCs around the country that have physical separation between the agencies however there are electronically connected and have the ability to exchange information almost as if they were in the same room. With this set-up, the benefits in terms of incident detection would be similar however there would not be the added benefits that come with the everyday interaction between the traffic engineers and the police.

Other alternatives that should be considered when the police are not able to co-locate in the TMC are to have mechanisms in place for the TMC to receive the 911 cellular calls. This could be via Computer-Aided-Dispatch terminals or other methods (*12*). Again this alternative would likely improve detection times, but not offer the benefits of personal interaction between the traffic engineers and the police. If either of these methods were used, efforts should be taken to form working relationships between the agencies. This could be done through training classes and exercises as well as post incident meetings.

Based on the survey results of the TMCs and the police, the police located in a separate facility may result in the following benefits:

1. Avoid the potential chaos and confusion of multiple agencies co-locating in the same place; and
2. Value of having full ownership of the activity to avoid conflicting priorities.

Recommendations

Based on the results of the survey and the information learned through the literature review, it is recommended that the TMC and the police co-locate whenever possible. Past experiences have shown that co-location will result in improved incident detection, response, and clearance times, improved understanding, trust, respect, and communication among agencies, better on-site management of incidents, improved sensitivities to each other's organizational objectives and responsibilities, improved coordination to the actual response to scenes and the monitoring of impacts of incidents, and shared operation of the TMC to allow for 24-hour operation.

If co-location is not possible, then the TMC and police agency should be electronically connected to allow for a seamless exchange of information. This could be combined with a 911-dispatch center located at the TMC. These methods will help to improve incident detection without the benefits of building working relationships between the traffic engineers and the police.

RECOMMENDATIONS FOR A MEMORANDUM OF AGREEMENT

When a TMC and a police agency make the decision to co-locate at the same facility, a memorandum of agreement is necessary to designate the roles and responsibilities of each agency in areas such as funding, operating, and maintaining the facility. It is very beneficial if the plan were put into a formalized agreement. This does not have to be a binding contract, but rather a formalized agreement to work together with mutually agreed upon goals. Without a formalized agreement, changes in the personnel will often result in a loss of coordination and failure to maintain the interaction between the agencies.

The following section will provide a basic list of items which should be included in a memorandum of agreement as well as other items which are optional, however may provide additional benefits if included.

The following items should be included in a Memorandum of Agreement:

- The purpose of the co-location and specification of mutually agreed upon goals shall be stated in the agreement;
- Defined responsibilities of each agency regarding funding, implementing, and operating the TMC shall be defined in the agreement;
- The police agency shall designate a liaison to the TMC to coordinate all activities;
- The TMC shall designate a liaison to the police agency to coordinate all activities;
- A plan for the agencies to work jointly to coordinate incident management efforts shall be defined in the agreement;
- A multi-agency decision making process shall be defined in the agreement;
- A dispute resolution protocol shall be defined in the agreement;

The following items may be included in a Memorandum of Agreement and may result in added benefits to the co-location agreement.

- The agencies may share communication technology and expertise and planned future communications infrastructure;
- The agencies may share responsibilities to allow for a 24-hour operation;
- The agencies may schedule and initiate post-incident critiques
- The agencies may schedule and initiate training exercises or mock incidents with other emergency responders;
- The police agency may conduct a security background check on any individual requesting access to the TMC.

IMPLICATIONS FOR HOMELAND SECURITY

Since September 11, 2002, homeland security has been a concern of people across the country. TMCs have been given much attention regarding the role they played on September 11th and what roles they can play in the future. The focus of the following section on what research is being done in this area, and the goals the government is trying to accomplish.

What is Being Done?

In the months following September 11th, much focus has been placed on the state of security on our nation's roadways, and on improving the existing level of security. In response to the terrorist attacks, President Bush created the White House Office of Homeland Security, and appointed former Pennsylvania Governor Tom Ridge as the director. In other efforts, the US Transportation Secretary Norman Mineta has set up the USDOT National Infrastructure Security Committee (NISC) whose goal is to focus on intermodal transportation security issues, the Transportation Research Board (TRB) has created a Task Force on Critical Transportation Infrastructure Protection, and the American Association of State Highway and Transportation Officials (AASHTO) has created a Task Force on Transportation Security (TFTS) (*17*).

What Are We Trying to Accomplish?

It is apparent by these efforts, that much emphasis is being placed on research into ways to protect our roadways, in particular what technology is necessary to help with this effort. The Federal Highway Administration's (FHWA) activities in surface transportation are aimed at ensuring that surface transportation operating agencies throughout the nation have the necessary tools, techniques, information, and understanding to be able to prevent, prepare for, respond to, and recover from natural and man-made

disasters (18). The goal of the research is to have operational policies, protocols, procedures, practices, and improvements in place within each region that will enable people and goods to move safely and effectively during threatening situations while still enabling emergency access to the scene, and to facilitate re-establishment of the transportation system after an emergency (18).

More specifically, some of the objectives that the FHWA is trying to accomplish are (18):

1. More fully engage transportation operators with emergency managers and public safety in regional collaboration, information sharing, for the management of transportation during an emergency;
2. Ensure development of a communications capability, with agreed to protocols, standards, and messages, to enable the transportation systems operators to communicate with law enforcement, fire and rescue, EMS, and other management officials;
3. Ensure that communications to the public, through the media and advanced traveler information systems, are an essential component of emergency management planning; and
4. Facilitate full information sharing capabilities of the transportation system, including ITS, to support emergency management planning and operations.

These objectives all involve coordination and communication between different agencies. Most of the emphasis will be put on the planning and operations at the TMC, which is why so much stress has been placed on this area.

The Six Stages

The research conducted by the FHWA and other organizations has been divided into six stages, based on the structure of the Office of Homeland Security: Detection, Preparedness, Prevention, Protection, Response, and Recovery (18). These stages, including the TMCs possible role in each stage, are discussed in the following section and are summarized in Table 1 at the end of the section.

Detection

Detection is described as the collection and distribution of intelligence information. The USDOT has been active in this area by assuring that intelligence moves between federal and state or local agencies. The USDOT has also put emphasis on “bridging the gap” between transportation agencies and law enforcement and emergency management (18).

The TMC can play a role in the detection process. The highway maintenance workers, who travel the roadways on a daily basis, can provide critical and timely detection of possible wrongdoing (6). AASHTO is currently working to develop materials to train and inform these workers. There are also operators at every TMC whose job is to monitor the transportation infrastructure via CCTVs. FHWA has been working on developing ways for the TMC to also monitor critical transportation infrastructure such as bridges and tunnels.

Preparedness

The process of being prepared for an attack begins with planning for one. The FHWA and ASSHTO are currently working to survey the state of emergency management plans, and to offer technical guidance on the “state-of-the-art” on emergency planning for threat scenarios (18). For these plans to be effective, they must be understood by all participants and practiced regularly. This is where interagency cooperation and coordination becomes important. For a plan to work effectively in the midst of a crisis, all of the key “players” must know each other and work together. If the agencies are already coordinating and/or co-located it is will make it easier to carry out an effective emergency management plan.

Prevention

The efforts in preventing future acts of terrorism have been visible in the areas such as freight movement and border crossings (18). This is the area that the TMC will be least involved in. However, ITS technologies are being researched to make improvements in area of prevention.

Protection

There are many different areas associated the protection of our transportation infrastructure. One area is to protect the information systems that the transportation agencies depend upon to carry out their duties (18). Another area is protection during special events. This area was carried out successfully during the 2002 Olympic Games in Salt Lake City. During the Olympic Games, transportation security was at an all-time high level with minimal impacts on the effectiveness of the transportation system (18). The security system was also designed such that travelers have adequate warning of travel conditions so that they could choose an alternate route if necessary. Recent research has suggested that the transportation agencies need to treat everyday as a special event in order to battle congestion and protect against any threats.

Response

Response is typically defined as what is done starting at the moment an emergency occurs until the emergency no longer exists. The FHWA states that one particularly critical element in response is the ability of agencies to communicate with one another (18). It is crucial that transportation agencies and public safety agencies such as police, and fire, and emergency personnel learn how to work together during emergencies that affect not only public safety but also the transportation network. The Virginia Department of Transportation (VDOT) Smart Traffic Center in Arlington had a crucial role in the response to the attacks on the Pentagon on September 11th. Utilizing the technology in the Smart Center, the HOV lanes heading south away from Washington were reversed and opened to all traffic. The area's traffic signal system was switched to "July 4th" mode to allow for maximum flow of traffic out of the area. VDOT utilized variable message signs to assist making the motoring public aware of detour routes. The area police also assisted VDOT by inspecting all the commercial trucks traveling through the tunnels in the area for added insurance. In the midst of the crisis, the VDOT continued to supply information to the news media and to update their website (18).

Recovery

Recovery has been defined as the events starting immediately after an emergency ends and can extend until weeks or months later depending on the extent of the emergency. During recovery, the agencies work to re-establish safe, reliable, and secure transportation on the roadways (18). The TMC can play a big role in recovery. ITS technology such as variable message signs and highway advisory radio can be deployed to make the public aware of road closures and alternative routes. The TMC will also serve as the central point for getting information to the public regarding traffic conditions on the network.

It is apparent that TMCs across the country need to be prepared in case of a terrorist threat or attack. To be prepared for all of the previously mentioned steps, there needs to be interagency coordination agreements.

Table 2. The TMCs Role During the Six Stages

The Six Stages (<i>18</i>)	Role of the TMC
Detection	<ul style="list-style-type: none"> • Highway maintenance crews monitoring daily • TMC operators monitoring transportation infrastructure
Preparedness	<ul style="list-style-type: none"> • Agency cooperation to develop of state-of-emergency management plans
Prevention	<ul style="list-style-type: none"> • Monitoring of border crossings
Protection	<ul style="list-style-type: none"> • Protect information systems that transportation agencies rely on to perform their duties
Response	<ul style="list-style-type: none"> • Utilize technology to efficiently to get people out of the affected area • Utilize technology to get emergency personnel into the affected area • Utilize technology to keep the emergency personnel, the public, and the media informed
Recovery	<ul style="list-style-type: none"> • Continue to keep the emergency personnel, the public, and the media informed of road closures, alternative routes, etc.

POLICE CO-LOCATION FOR HOMELAND SECURITY NEEDS

As stated previously, various TMCs and police agencies were surveyed to determine the benefits of police co-location at the TMC. Furthermore, the survey also covered topics concerning the implications for homeland security. The purpose of the survey was to gain information on the following topics.

- What role should the TMC play in the case of a homeland security threat;
- What benefits are there to having coordination between the police and the TMC; and
- What coordination or co-location agreements need to be in place to be adequately prepared?

Extensive research has been underway since September 11th to identify ways to protect our transportation system in case of a terrorist attack. There are many ways in which the transportation system can be affected. When the World Trade Center and the Pentagon were attacked, the focus was on quickly getting people out of the area. In another scenario, if the country were attacked by bioterrorism, there may be a need to get people quickly into an area with vaccines or to get people out of an area to receive vaccines. The transportation infrastructure itself is also at risk because of its vast, extensive network, and its ability to carry thousands of people at once. These are examples of the various scenarios for which the TMC is trying to become prepared. The TMCs and police that were surveyed stated the following opinions about the TMCs most important jobs during a homeland security attack.

Role of the TMC

Based on the survey responses from various TMCs, there are many different ways the TMC personnel feel they could be effective during a homeland security threat. The information in this section is the

thoughts of the TMC personnel on how the TMC could be of assistance during a homeland security threat or attack.

Surveillance

The TMCs have the technology to provide real-time surveillance for law enforcement via detectors and CCTVs (16). However, before this can be used effectively, there needs to be a basis for threat assessment. Also there needs to be further research on methods of surveillance. For example if the technology at the TMC such as CCTVs were utilized to watch a bridge, what part of the bridge do you watch? These are the types of questions that are currently being raised by the TMCs and are being researched by the FHWA and other organizations.

Another type of surveillance that the TMC feels is important is that of the DOT personnel. They travel the roadways daily and are aware of abandoned vehicles of any changes to the public infrastructure (6). However, they need to be trained in what to look for.

Traffic Management

The TMCs pure existence is to manage traffic on the roadways. There are many ways that the TMC can assist during a homeland security threat or attack. Some examples of this include reversing HOV lanes and changing signal timings to allow for the maximum flow of vehicles away from the emergency. The TMC can also utilize variable message signs to alert drivers to alternate routes (14). This was seen on September 11th immediately following attacks when variable message signs outside of New York City read, "Avoid Manhattan".

Provide Information to the Police and the Public

A very important role of the TMC will be to provide information to the police, the motoring public, and the media. The TMC can use resources such as variable message signs, highway advisory radio, and the Internet. The TMC can also use the partnerships with the broadcast media to get information out through the television and the radio (12).

Benefits of Coordination Between the TMC and the Police

Surveillance

Surveillance is an important benefit to coordination between the TMC and the police. The police can have access to the real-time surveillance that is currently occurring on highways and could potentially occur on other transportation infrastructure(16). If the police are working in the TMC, they can see first-hand any suspicious activity and then dispatch the appropriate team to respond.

Traffic Management

Emergency response for virtually every emergency situation is dependent upon being able to get into the affected areas. The DOT will most likely be the agency directly involved in leading the way to open blocked roads or to route around unfixable blocks (6).

Providing Information

Just as importantly as keeping the public informed, the TMC can keep the police informed of traffic conditions. It is important for the police to be able to receive fast and accurate information so that they will be able to perform their enforcement activities.

What Coordination/Co-Location Agreements are Necessary?

Make a Plan

The TMCs and the police agree there is a need for a plan of action. It is not possible to plan for every conceivable incident, so the plan needs to be flexible and the agencies need to have the power to improvise when necessary (16). The development of this plan may evolve from “table-top” discussions between all of the involved agencies. The plan should be reviewed regularly and updated when new threats arise. It is very beneficial if the plan were put into a formalized agreement. This does not have to be a binding contract, but rather a formalized agreement to work together with mutually agreed upon goals. Without a formalized agreement, changes in the personnel will often result in a loss of coordination and failure to maintain the interaction between the agencies.

Practice the Plan

A plan will not be effective if all the involved parties do not practice it regularly. Therefore, mock incidents should be staged to practice putting the plan into action. Aside from mock exercises, the agencies will benefit from practicing incident response together in a daily environment (16). This will aid in the development of working relationships between the different agencies as well as improve incident management on a daily basis.

Establish a Person-In-Charge

It is important to establish a person in charge of security at each agency. Command and control is a central issue in the closing and opening bridge, tunnel, and turnpike facilities (17). Although there are many agencies involved in the response to an attack, someone must have the authority to answer questions such as: “Do we shut down now?”, “Can we reopen yet?” This will help to avoid any added confusion during an attack.

Establish a Command Center

A joint operations center should be established so that the key responders can talk to each other face-to-face and make joint decisions (16). The TMC can be an ideal location for a command center. The TMC is already set up to monitor the roadways and has the necessary devices already in place to communication with other agencies, the public, and the media.

Communicate with the Each Other and the Public

Communication is key during a crisis. The agencies need to provide frequency and accurate updates on their actions to each other. Again, this constant communication will be easier if the agencies are co-located or else all report to the command center when a threat or attack occurs.

SUMMARY OF FINDINGS

The following findings regarding homeland security are based on the results of the survey questionnaire of the TMCs and police agencies and the literature review discussed in the previous sections.

The TMC can perform the following functions to prepare for and respond to a homeland security attacks: surveillance, traffic management, and providing information to the public. These functions, if coupled with coordination and cooperation with the police, can provide many benefits to the police agency. Some of the benefits may include the following.

Table 3. TMCs Functions During a Homeland Security Attack

Benefit	Role of the TMC
Surveillance	<ul style="list-style-type: none"> • Allow the police to access real-time surveillance information • The police can access the threat and respond to events seen in the real-time surveillance video
Traffic Management	<ul style="list-style-type: none"> • Allow police access into affected areas • Keep motoring public away from affected areas • Utilize technology to efficiently get people out of the affected area
Provide Information	<ul style="list-style-type: none"> • Utilize technology to keep the police and the public informed of alternative routes, road closures, etc. • Continuously provide information via news media and a website

In order to be adequately prepared for a homeland security attack, the following steps need to be taken to maximize the benefit of coordination between the TMC and the police.

1. Make a plan;
2. Practice the plan;
3. Establish a person-in-charge
4. Establish a command center; and
5. Communicate with each other and the public.

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- Glen Carlson, Minnesota DOT;
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APPENDIX A – SURVEY FORM FOR NO CO-LOCATION OF POLICE AT TMC

Please fill out this survey if not police are not currently co-located at the TMC.

TRAFFIC MANAGEMENT CENTER NAME: _____

1. What agencies are located at your TMC?
2. Who are your other operational partners not co-located at the TMC?
3. What police agency/agencies are responsible for the roadways that are maintained/operated by the TMC?
4. How do you communicate with the police currently?
5. What problems or disadvantages do you have in exchanging information?
6. Do you have a good working relationship?

7. Have time delays incurred when police input is needed for a decision?
8. Would incident detection times decrease by having the police located at the TMC?
9. Could the police operate the TMC during off-hours (if applicable)?
10. Would you like the police or a representative located at the TMC?
11. Do you feel that the police and traffic engineers have different priorities that could cause conflict?
12. Do you see any benefits to the police **not being** located at the TMC?
13. What role do you see the TMC playing in the case of a homeland security threat?
14. What benefits do you see to having coordination between the police and the TMC in case of a homeland security threat?
15. What coordination/co-location agreements do you think need to be in place in the case of a homeland security threat?
16. Could you provide any referrals for further research with the police?

Thank You For Your Help With This Research!

APPENDIX B – SURVEY FORM FOR CO-LOCATION OF POLICE AT TMC

Please fill out this survey if the police are currently co-located at your TMC.

TRAFFIC MANAGEMENT CENTER NAME: _____

1. What agencies are located at your TMC?
2. What police agency/agencies are responsible for the roadways that are maintained/operated by the TMC?
3. Who are your other operational partners not co-located at the TMC?
4. Do you work side by side with the police at the TMC?
5. Do you feel that the police and traffic engineers have different priorities that could cause conflict?
6. How is the decision making process handled between the multi-agency representatives?
7. Is there an agreed upon dispute resolution protocol available when disagreement on how to best respond/handle an incident occurs between the agency representatives?
8. What benefits do you see to the police co-locating at the TMC?
9. Do you see an improvement in incident detection?
10. Do the police assist you in off-hours (if applicable)? If so, how?
11. Is there a good working relationship?
12. What role do you see the TMC playing in the case of a homeland security threat?
13. What benefits do you see to having coordination between the police and the TMC in case of a homeland security threat?
14. What coordination/co-location agreements do you think need to be in place in the case of a homeland security threat?
15. Could you provide any referrals for further research with the police agencies that are located at your TMC?

Thank you for your help with this research!

APPENDIX C – SURVEY FORM FOR POLICE CO-LATED AT TMC

Survey for police agencies co-located at the TMC.

Police Agency Name: _____

1. Are the police or a representative of the police currently located at the traffic management center?
2. How many police are located at the TMC?
3. What brought about this co-location agreement and what were the goals of this arrangement?
4. Do you work side by side in the same room as the traffic engineers?
5. How is the decision making process handled between the multi-agency representatives?
6. Do you feel that the police and traffic engineers have different priorities that could cause or have caused conflict?
7. Is there an agreed upon dispute resolution protocol available when disagreement on how to best respond/handle an incident occurs between the agency representatives?
8. Do you see the benefit of the value added by having a professional traffic engineering expertise as part of your protocol?
9. What other benefits do you see to the police co-locating at the TMC?
10. Is there a good working relationship?
11. How do you think the TMC could assist you during a homeland security threat?
12. Do you see any benefits of having coordination with traffic engineering professionals during a homeland security threat?
13. What coordination/co-location agreements do you think need to be in place in the case of a homeland security threat?

Thank you for your help with this research!

APPENDIX D – SURVEY FORM FOR POLICE NOT CO-LOCATED AT TMC

Survey for police agencies not co-located at the TMC.

POLICE AGENCY NAME: _____

1. Are you currently located or have a representative located at the traffic management center (TMC)?
2. How do you contact the TMC if you need assistance (By phone, computer...)?
3. Is there a significant time delay in getting the assistance that you need?
4. Would you like to see the police being co-located at the TMC? If so, what benefits do you see to this arrangement?
5. Do you see any benefits to being located elsewhere?
6. Do you feel that traffic engineers and the police have different priorities that could cause or have caused conflict?
7. Do you see any benefits to having the expertise of a traffic-engineering professional as part of your protocol?
8. In particular, do you see any benefits of having coordination with traffic engineering professionals during a homeland security threat?
9. How do you think the TMC could assist you if there was a homeland security threat?
10. What coordination/co-location agreements between the police and the TMC need to be in place in the case of a homeland security threat?

Thank you for your help with this research!

ANNA TERESE GRIFFIN



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She is currently pursuing a Master of Engineering in Civil Engineering at Texas A&M University. She is currently employed as a Graduate Research Assistant at TTI where she is involved in access management research. Anna has been active in the Institute of Transportation Engineers since 1999 and is currently serving as the Public Relations Director for the Texas A&M University student chapter. While at Michigan State University she was also active in the National Society of Professional Engineers (NSPE), Tau Beta Pi and also studied transportation engineering in Russia for five weeks. Anna's areas of interest include transportation planning and intelligent transportation systems.

CRASH REDUCTION DUE TO THE INSTALLATION OF RED LIGHT CAMERAS: GUIDELINES FOR SITE SELECTION

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SUMMARY

Each year more than one million crashes occur at signalized intersections in the United States. Red light running was cited as the cause for 106,000 crashes, 89,000 injuries and about 1,036 deaths in the United States in the year 2000. In order to address the ever-growing problem of red light violators, some city governments and police departments have turned to automated enforcement.

Traditional traffic enforcement requires a police officer to see the violation and then pursue the perpetrator in order to issue a violation. Not only is this costly in the terms of deployment, but it is also hazardous for the police officer and the surrounding motorists as the officer may have to speed and run lights in order to catch the violator. The use of automated enforcement technology is a possible solution to the issue of safety and deployment costs. In countries such as the Netherlands and Australia, automated enforcement has decreased the number of red light violators by 35 to 60 percent and reduced right-angle crashes by 32 percent. Similar decreases in violations have also been observed in the United States. In New York City, NY; Howard County, MD; and San Francisco, CA; the number of violations decreased 20, 23, and 40 percent respectively. The major issue is whether or not the decrease of red light violators correlates to the reduction in crashes at intersections. From the literature review it can be inferred that red light cameras have an impact on reducing the amount of crashes and injuries at intersections. An e-mail survey was completed to evaluate the criteria utilized for the installation of red light cameras at intersections. Draft guidelines were developed from these criteria and were reviewed by a review committee. Upon the recommendations of the committee the final guidelines were produced. The final guidelines are as follows:

1. Accident History
2. Red Light Citation History
3. Approaching Speeds
4. Traffic and Pedestrian Volumes
5. Intersection Degree of Saturation
6. Perceived Benefit to Cost

Based on these guidelines and the implementation guidelines from previous research, it is the goal that these guidelines be utilized to aid communities in developing countermeasures for red light running and identifying proper locations for the installation of red light cameras should all other counter measures fail to curtail the red light violations.

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INTRODUCTION

Each year more than one million crashes occur at signalized intersections in the United States (1). Red light running was cited as the cause for 106,000 crashes, 89,000 injuries and about 1,036 deaths in the United States in the year 2000 (2). In order to address the ever-growing problem of red light violators, some city governments and police departments have turned to automated enforcement. The common definition of a red light violation is defined as when the front wheels of a vehicle enter the defining boundary of an intersection after the traffic signal changes to the red phase, and the vehicle proceeds through the intersection (3). The defining boundary of an intersection is usually the stop bar or crosswalk. This definition may vary slightly from state to state as each state creates its own traffic laws.

Under traditional traffic enforcement a police officer is required to see the violation and then pursue the perpetrator in order to issue a violation. Not only is this costly in the terms of deployment, but it is also hazardous for the police officer and the surrounding motorists as the officer may have to speed and run lights in order to catch the violator. The use of automated enforcement technology is a possible solution to the issue of safety and deployment costs. In countries such as the Netherlands and Australia, automated enforcement has decreased the number of red light violators by 35 to 60 percent and reduced right-angle crashes by 32 percent (3). Similar decreases in violations have also been observed in the United States. In New York City, NY; Howard County, MD; and San Francisco, CA; the number of violations decreased 20, 23, and 40 percent respectively (3). The major issue is whether or not the decrease of red light violators correlates to the reduction in crashes at intersections.

Automated enforcement has been in use in the United States since the early 1990s and has had success in reducing the number of violators, but has run into criticism (4). Opponents claim that such systems violate a variety of constitutional and legal protectants. To date there is not a provision in the law that guarantees the right to privacy while operating a motor vehicle. In *Katz vs. United States* the U.S. Supreme Court ruled, "What a person knowingly exposes to the public, even in his own home or office, is not a subject of Fourth Amendment protection" (5).

In March 1998, the Institute of Transportation Engineers' (ITE) Traffic Engineering Council developed a draft position (6). The statement as issued is

"...the use of image capture technology to monitor and enforce traffic laws, regulations or restrictions. Where enabling legislation authorizes the use of automated enforcement, the image capture technology negates the need for a police officer to directly witness a traffic offense." (6,7)

In 1999, 90,000 injuries and approximately 950 deaths in the U.S. were attributed to red light running (8). Due to gravity of this problem it is essential that intersections can be evaluated for possible deployment of automated enforcement systems. The value of life is impossible to correlate to other economic costs that result from crashes. The deployment of automated enforcement systems along with other engineering countermeasures, it is the hope that such statistics will decrease.

Research Objectives

- The main goal is to determine whether the use of photo enforcement reduces the amount of crashes at intersections where it is installed. The stretch goal of this paper is to conduct a peer review of the draft warrants developed for the selection of a site for the installation of automated enforcement technology. In order to achieve these goals the following objectives will be completed: Verify the correlation between red light violations and accidents;
- Demonstrate experience with reduction in violations using automated enforcement technology;
- Demonstrate experience with reduction in crashes due to the use of automated enforcement technology; and

- Develop a set of draft guidelines for the selection of sites for the potential installation of automated enforcement technology.
- Modify draft guidelines to create final guidelines thru suggestions from a peer review.

Scope

This research was limited to the municipalities that have or are currently deploying automated enforcement technology in order to combat red light running. Included in the research was a survey of the existing criteria/ guidelines used in order to qualify an intersection as a potential candidate for red light cameras. This survey was carried out by the use of first telephone contact to insure that the survey was sent to the right individual, and second by sending the survey by email. The individuals contacted are those who work very closely with the installation of red light cameras.

STUDY DESIGN

The following discussions are of the three primary procedures that are necessary to successfully complete the research objectives of this research. The three procedures are:

- Literature Review
- Personal Contact
- Guideline Development

Literature Review

The researcher reviewed past and current literature available in order to examine the results of the use of automated enforcement. This review will serve to identify the number of violations, characteristics and prevailing conditions of the intersection, the number of accidents before, the number of accidents after, and the current law in effect. Also the review will facilitate the next step by identifying municipalities that have or are currently using automated enforcement technology.

Personal Contact

A contact list will be created to assist in the gathering of information from cities that have automated enforcement in use. The list will include city engineers, police departments, consultants, and planners. The email survey will be the primary tool used to assemble the criteria used by cities to choose intersections for the deployment of automated enforcement technology. The survey will also inquire about the willingness of the individual to participate in the peer review. The survey will be sent to the contacts above with the purpose to gain insight into the factors used for selection of intersections for photo enforcement deployment. The survey questions are as follows:

- Does your department/ company have a set of criteria for choosing intersections for the installation of red light enforcement systems? If so, what are the criteria you use?
- If not, how do you choose one intersection over another?
- What are the traffic volumes at the intersections where the systems are installed?
- Has there been an evaluation of the effect of the red light enforcement systems on the crashes at the intersections where it is in use? If so, what types of crashes have decreased (i.e. right-angle, rear-end collisions)? Has there been an increase in any particular type of crashes?
- I will be conducting a peer review in mid July. Would you be willing to participate?

Guideline Development

Guidelines for the deployment of future automated enforcement systems will be created from the information compiled. The purpose of the guidelines is to provide requirements for the satisfaction of engineering concerns. Along with this data, the input from those with experience with these systems will be review and included. In order to assure that the developed guidelines are as thorough and applicable as possible, the guidelines will be sent to the contacts for review. The contacts will be asked to provide suggestions for revisions to the guidelines. The guidelines will include the following criteria:

- Crash History
- Intersection Type
- Approach Grades
- Traffic Volumes
- Posted Speed
- Vehicular Mix

BACKGROUND

In this section of the paper, there will be a brief review of the history, benefits, and issues concerning red light running enforcement. The information provided has been summarized from the articles reviewed during the literature review.

History of Red Light Running Enforcement

A camera designed for mounting in a police car, in order to photograph traffic violations, was produced by a German firm in 1955 (9). However, it was discovered that a photograph alone could not provide sufficient evidence. As a result, experimental work to combine speed radar and the camera was enacted in the late 1950s and early 1960s. The use of automated enforcement technology to combat red light running has been used in many foreign countries since the 1970s (9). Specifically, red light cameras of one manufacturer have been used in 33 countries since the 1970s.

Automated enforcement systems have been used extensively in Western Europe and Australia. After a successful trial run in 1981 in Victoria, Australia, the installation of red light cameras began in 1983 with 10 cameras. Currently, there are 35 cameras, which are rotated between 135 intersections in the Melbourne metro area (10).

Benefits of Red Light Running Enforcement

There are several benefits that proponents associate with the use of red light cameras. They are: increase traffic control law compliance, increased traffic safety, and increased safety and cost-effectiveness of enforcement activities. The general assertion is that as the number of traffic violators' decrease, the number of crashes and therefore injuries and deaths associated with them also decrease. Red light cameras enable the enforcement of intersections on a continual basis. Traditional law enforcement methods cannot only be costly, but are greatly influenced by the availability of enforcement personnel.

Why do drivers disobey traffic signals? There are many reasons, though four critical issues are: failure to control speed, driver impatience, driver impairment, and poor signal timing. A study by the FHWA states that fifty-eight percent of Americans admit to running a red light (11). The objectives of automated enforcement as stated by an FHWA representative are (11):

- Reduce traffic crashes and dangerous driving.
- Save lives.

- Reduce health care costs.
- Increase police officer safety.
- Respond to public concerns.
- Create violator-based revenue for increased public safety.

From reviewing the literature, Table 1 was developed to summarize the effects of red light cameras with the change in violations and injuries.

Critical Issues

Failure to control speed is a contributing factor to many highway crashes as it is in many intersection crashes. Speeding is perceived as a problem in many communities, and when the complicated addition of an intersection is included in the problem the result may be the violation of a red indication and possible crash. There is a dangerous saying, “Green means go, yellow means speed up, and red means stop unless you can make it without hitting anyone.” Driver’s perception of external stimuli is slowed with age, impairing drugs like alcohol or antihistamines (found in many allergy medicines), and with increasing speed. As a vehicle increases speed the field of vision of the driver narrows. This may lead to misinterpretation of external stimuli or missing them all together.

In today’s busy society, there are two overwhelming concepts: time is money and there is never enough time. Driving is usually viewed as a part of an individual’s daily routine, and with the ever-increasing amount of congestion the task of getting from one place to another is complicated. Today, an individual’s vehicle is much more than transportation. It is an extension of the person where the space occupied by the vehicle can most closely be described, at least from the driver’s perspective, as “their space”. Psychologists agree that the cause for much of driver’s impatience or aggression toward other drivers is due to the perceived violation of their space (12).

There can be several reasons why a driver may be impaired. The driver may be under the influence of legal or illegal drugs. For example, there are many prescriptions, which may cause drowsiness, slow down a person’s reactions, or affect their vision. Furthermore, alcohol greatly reduces the motor functions of the brain. The task of driving a motorized vehicle is greatly complicated when the driver is less than fully coherent. Another impairment may be due to distractions of the driver. These included but are not limited to: adjusting the radio or CD changer, answering or talking on a cell phone, disciplining or correcting children, external vehicle distractions, visual clutter in the roadway, and putting on makeup/shaving while driving, etc.

Poor signal timing can be due to changes in speed limits or other factors such as roadway realignment. Also driver may exhibit a differential behavior in understanding the yellow indication as the statutory obligation varies from state to state (23). A myth held by many individuals is that the development of a timing plan for a signal is rather easy. On the contrary, the development of a good signal-timing plan takes time and effort. All signals should have their signal timing plans updated to insure of good timing and proper progression between signals. There is little that is more frustrating for a driver than to be stopped at every light.

Table 1. Red Light Crash Summary

Location	Year of Installation	Change in Violations	Change in Crashes (Total, Rt. Angle, Rear End)			Change in Injuries
Boulder, CO (<u>13</u>)	1999	- 37 %	- 57 %	NA	NA	NA
Charlotte, NC (<u>14,15</u>)	1998	- 20 %	- 19.0 %	- 60.1 %	- 4.3 %	NA
Howard County, MD (<u>19</u>)	1996	- 48 %	- 21 %	-38.5 %	-12.6 %	NA
Fairfax County, VA (<u>16</u>)	NA	- 44 %	NA	NA	NA	NA
New York City, NY (<u>13</u>)	1992	- 34 %	NA	- 60 % to - 70 %	NA	NA
Oxnard, CA (<u>17</u>)	1997	- 42 %	- 20 %	- 32 %	NA	- 46 %
San Francisco, CA (<u>13</u>)	1996	- 42 %	NA	NA	NA	NA
Scottsdale, AZ (<u>13</u>)	NA	- 62 %	NA	NA	NA	NA
United Kingdom (<u>18</u>)	NA	- 55 %	- 7 %	NA	NA	- 10 %
Victoria, Australia (<u>18</u>)	1983	-35 % to - 60 %	- 6.7 %	- 32 %	- 30.8 %	-10.4 %
Wilmington, NC (<u>13</u>)	2000	-40 % to - 60 %	- 22 %	- 26 %	- 8 %	NA

From the results shown in Table 1, it can be inferred that red light cameras have an impact on reducing the amount of crashes and injuries at intersections. Crash statistics are incomplete from many areas due to the short duration of their installment. Both Australian and British sources, with 30+ years experience each, recommend on avoiding any conclusion with regard to crashes until five years of data have been obtained (19). This time period permits stabilization of the “regression towards the mean” phenomenon to proceed. The phenomenon is defined as the tendency of things to gravitate towards the center of a spectrum, as long as they start on either end and have the ability to fluctuate (20).

Issues with Red Light Running Enforcement

It is argued that red light cameras violate personal privacy, violate constitutional rights, are not as effective as other means of enforcement, costs outweigh the benefits, and sole purpose is to generate revenue. Violation of privacy and constitutional rights are often used to support opponents’ claims against the use of automated enforcement. Yet to date there is no court case that has specifically defined an individual’s right to privacy under the First Amendment in regards to the operation of a vehicle. In retrospect it is unreasonable to consider that the act of driving a motorized vehicle would fall within the protected area of personal privacy. This is due to several reasons. First of all, the action of driving takes place in public view and is heavily regulated. Secondly, the right to drive is a privilege not a right since it is not guaranteed to every individual as an intimate right (9). Furthermore, in *Katz v. United States* the U.S. Supreme Court ruled that what a person knowingly exposes to the public, even in his own home or office, is not a subject of Fourth Amendment protection (9).

The primary charge in the assertion that red light cameras sole purpose is to generate revenue is based on the accusation that organizations responsible for maintaining the intersection safety codes have altered the regulations specifically to accommodate camera enforcement and decrease yellow times (21). This accusation is false. The author uses two separate goals and objectives from the 1985 and 1989 Green Book coupled with the inclusion of the red clearance interval. Basically, the argument is that ITE deliberately changed recommended practices to solely benefit automated enforcement. The paper appears to be a tirade of twisting facts in order to support an initial opinion. On the contrary, it has been proven that signal-timing procedures are beneficial and as accurate as possible.

CURRENT SYSTEMS

The Insurance Institute for Highway Safety (IIHS) lists about 70 communities in the United States that are currently using red light cameras for enforcement. These communities vary in size and geographic features yet all have established a similar concern for the reduction of crashes at intersections in their area. To date there is no set of warrants to follow when selecting sites for the installation of automated enforcement systems, though there has been a fair amount of research devoted to this area of interest. The systems in place have similar characteristics though the technology, data collection, and penalties do vary from state to state. California and Maryland have the largest numbers of communities using red light cameras with 21 and 20 cities each respectively. Table 2 lists the operating vendors, fines, and revenue distribution for seventeen United States cities.

Technology

In general, a red light camera system is composed of three parts: the vehicle sensor, the camera, and the processing device. The types of sensors that are available are inductive loops, coaxial cables, piezoelectric sensors, roadway rubber tube sensors, video imaging, and infrared beams. The type of sensor used is largely dependent on the processing device that is chosen. There are three types of cameras that are used. They are video imaging, digital, and 35-mm cameras. Each camera has its own pros and cons though 35-mm and all have the ability to be moved from one location to another. While each system may have differences, all systems share the following common attributes: (3)

- Ability to capture, transmit, process, store, and recover captured images so that data may be managed in an efficient manner;
- Sufficient resolution to satisfy court standards for the image-reading of vehicle license plates, clear detail of the vehicle, and identification of the vehicle operator (if necessary);
- Capability to prevent the spreading of overexposed portions of an image (anti-blooming) that may result from vehicle headlights or sunlight from highly reflective surfaces;
- Adequate differentiation of light to dark areas within an image to provide necessary details (also referred to as contrast latitude);
- Ability to provide blur-free images of moving vehicles;
- Ability to detect at varying levels of light;
- Image enhancement circuitry to eliminate major sensor defects such as bright or dark columns, which detract from the visible presentation of an image;
- Continuous read-out of images to support monitoring along with single frame capture capability for recognizing several successive vehicles committing violation; and
- Ability to be moved to different locations or to be mounted into a permanent position.
- Components that are environmental friendly.

Legislation

For the majority of areas in which automated enforcement has been started, there has been enabling legislation passed at the state level. As there is always an exception to the rule, the same is true here.

Table 2: Automated Enforcement fines (13)

City	Fine	Fine Distribution	Vendor
Baltimore, MD	\$75	15%-35% of fine to vendor	Lockheed Martin
Charlotte, NC	\$50	1 st notice: \$28 vendor, \$22 city	Lockheed Martin
	\$50	2 nd notice: \$23 vendor, \$27 city	
	\$100	3 rd notice: \$76 vendor, \$26 city	
Fairfax, VA	\$50	\$20.85 vendor, \$29.15 city	USPT
Garland, TX*	\$75	\$74.50 vendor, \$0.50 city	Lockheed Martin
Greensboro, NC	\$50	\$35 vendor, \$15 city	Peek Traffic
High Point, NC	\$50	\$35 vendor, \$15 city	Peek Traffic
Howard County, MD	\$75	Sliding scale. State receives no revenue.	Traffipax/EDS
Lakewood, WA	\$71	NA	NA
Marietta, GA	\$70	NA	LaserCraft
Mesa, AZ	\$170	\$74.01 state, \$47.49 city, \$48.50 vendor	Lockheed Martin
Oahu, Hawaii	\$77	As much as \$50 vendor, \$27 city	Lockheed Martin
Phoenix, AZ	\$175	\$93 vendor, \$82 city	Lockheed Martin
San Diego, CA	\$271	\$70 vendor	Lockheed Martin
San Francisco, CA	\$271	\$123 state, \$48.50 vendor, \$99.50 to further program, educational campaign, and equipment vendor	NA
Santa Rosa, CA	\$271	\$100 vendor	NA
Washington, DC	\$75	\$26 vendor (as much as 40%), \$49 city	Lockheed Martin
Wilmington, NC	\$50	\$35 vendor, \$15 city	Peek Traffic

* Automated enforcement program in the start-up phase.

Paradise Valley, Arizona passed a city ordinance allowing the use of automated enforcement systems to be used for the detection and validation for driving less than 20 mph over the posted speed limit. This followed an action by the Arizona Legislature, which changed this offense from a misdemeanor to a civil infraction. Other cities in the state have followed this.

As of June 2002, there are twelve states in the United States with legislation that allows the use of automated enforcement and three states that have no specific statute in place but use a form of automated enforcement (22). Generally, most of the legislation applies to automated enforcement of red light violations, though some states have legislation for automated enforcement of speed and a few for any offense for which it is appropriate. Each state may differ in liability, imaging, penalties, and defenses of red light violations. The type of imaging required can be set by the liable party but is not necessarily always the case. Usually the owner of the vehicle is liable, but in some states the driver is liable or the issue is not addressed. A major part of conflict is the penalties assessed. In all cases there is some amount of monetary fine, though in some areas points are assessed for insurance purposes.

CURRENT CRITERIA FOR SITE SELECTION

To date there has been little done in the area of developing criteria or warrants for the selection of sites for the installation of red light cameras. Though there have been a few papers on policies or recommendations for the implementation of automated enforcement for red light running, there is still need for a uniform set of criteria to aid traffic engineers and cities in the site selection process (23).

Policies and Recommendations

Miltazzo, et. al. established eight recommended stages for the implementation of red light running countermeasures. They recommend, as does the ITE-FHWA Red Light Running Steering Committee, that before any red light camera is installed that a full engineering investigation should take place. Photo enforcement is only a potential tool to be used as a countermeasure. The recommendations are listed below (23):

1. Conduct a traffic engineering study to verify the existence, extent, and causes of the problem.
2. If feasible, implement engineering countermeasures.
3. Consider implementation of traditional enforcement measures, perhaps with “rat boxes.”
4. If engineering countermeasures and/or traditional enforcement proves to be unsuccessful or unfeasible, then select appropriate red light camera locations.
5. Choose a financing agreement to insure that public safety will remain the primary goal.
6. Conduct a detail, perpetual public information and education effort regarding the program.
7. Implement red light cameras at intersections with the highest potential for crash reduction benefits.
8. Monitor intersections with cameras, indeed all countermeasures, for progress over time.

Survey Results

The results from the email survey can be found in Table 3. There were some general similarities in the criteria used though there were some differences. The response from the survey was 80.0 %, as 12 out of 15 replied, though 3 replies were from individuals that were unable to help due to no system installed. This can possibly be attributed to the initial telephone contact and/or the high interest in the research topic. The survey showed that the three most commonly used criteria are the history of red light crashes, red light citations, and engineering issues associated with intersection.

Further examination of the survey results, shows that there is a wide range of issues of concern when looking at the selection of a site for camera installation. Some of the issues are indicative of policies. For example, the history of red light citations shows where the limited police resources have been focused rather than the overall picture. However, the areas of police enforcement are chosen due to the history of red light running, public complaints, and crashes indicating a problem with red light running (i.e. right angle collisions). All of the criteria received from the survey are good measures of the extent of an existing problem, though some are more opinion-based than fact based. In the development of the guidelines, all of the criteria were considered. The draft and subsequent final guidelines are a synthesis of major issues.

GUIDELINES

Guidelines are a suggested set of instructions that *should* be used. They are developed using successful experiences with similar situations. Guidelines are used when a policy would be too limiting or confining, or for situations that are highly variable. They allow careful assessment of intersection conditions that are indicators for the need of traffic control devices or engineering countermeasures. The following guidelines, developed by the author of this paper, are intended for the site selection of intersections for the installation of photo enforcement systems. They have been developed by analyzing

the survey results and from the findings of the literature review. These are to be used along with the previous recommended stages for the implementation of red light running countermeasures. The implementation of these guidelines signifies that traditional enforcement and other engineering countermeasures are not sufficient for solving the problem.

Table 3. Red Light Crash Summary

Location	Red Light Running Crashes	Red Light Running Citations	Physical Obstructions	Engineering Issues ¹	Area Wide Coverage	Public Issues ²	Preliminary Review
Charlotte, NC	Yes	No	Yes	Yes	Yes	Yes	No
Fairfax City, VA	Yes	Yes	Yes	No	No	Yes	No
Howard Co., MD	Yes	Yes	No	Yes	No	Yes	No
Montgomery Co., MD	Yes	Yes	Yes	Yes	No	No	No
Oxnard, CA	No	No	No	Yes	No	No	Yes
Phoenix, AZ	Yes	Yes	Yes	No	Yes	No	Yes
Santa Monica, CA ³	Yes	Yes	No	Yes	No	Yes	No
Scottsdale, AZ	Yes	No	No	Yes	Yes	No	No

¹Includes Traffic Volumes, Collision Rates, Correctible Crash Patterns

²Includes Public Safety, Public Inquiries, Costs, City Government Suggestions, Police Input

³Program not installed yet.

Major Guidelines

Guideline 1, Accident History

Just like the presence of mold signifies the end of a products useful life, so the history of crashes signifies the presence of a problem with an intersection. The type of crashes that is most often tied to red light running is right angle crashes. These crashes often result in serious injuries or even deaths due to the fact that the side of the vehicle is the most vulnerable section. First of all, a traffic engineering study needs to be conducted in order to identify the extent, existence, and causes of the problem. The use of accident statistics can be helpful in this area, though the author disagrees with the total reliance on them alone. Accident statistics should be used to identify problem areas that need to be investigated further.

Guideline 2, Red Light Citation History

The evidence that there is a problem is a good indicator that countermeasures need to be implemented. Usually the presence of these citations is more of an indicator of allocation of available police resources and the relative safety of enforcing the law. Nevertheless, this is a red flag that should alert one to possible problem intersections though others may exist. Also to be included are areas when there is a high amount of complaints of red light running.

Many of the red light camera programs in the United States are collaboration between law enforcement and traffic engineers. Consequently, the author views the installation of red light cameras as an extension of the existing law enforcement activities. A good approach to quantifying these complaints is through public meetings, where there is dialogue between the citizens, police, and engineering communities.

Guideline 3, Approaching Speeds

From general kinetic principles we know that vehicles with greater speeds contain larger potential kinetic energy, which must be dissipated in order for the vehicle to stop. In order to apply this guideline there is a need to quantify what is meant by “greater” speeds. In 1964, David Solomon developed a series of parabolic curves that indicated the relationship between vehicle speeds and crash incidence. Furthermore, it was concluded that for travel speeds near the mean speed of traffic crash rates were lowest, and with larger deviations above and below the mean the crash rates increased (24).

Additionally, the curves denoted that a 10 mph deviation between the average speed and 85th percentile resulted in a significant increase in accident potential, which is similar to a relationship that has been detected between red light running occurrence and a 10 mph differential (25). The problem arises when an approaching vehicle violates a traffic signal creating the potential for a crash. Also as the speed increases, the severity of resulting crashes increases as well. There may be situations where there are high approach speeds and high violations, but few crashes. These areas need to be further evaluated and closely monitored for possible development of crashes.

Minor Guidelines

Guideline 4, Traffic and Pedestrian Volumes

Generally higher traffic volumes relate to a greater probability of violations and accidents. This is of particular concern when the cross-street traffic volumes are also high as well. While the crash of two vehicles can result in either injury or death, the same is not true of a vehicle-pedestrian collision. Intuitively, the pedestrian is almost always killed or severely injured when a vehicle runs a red light and collides with them. Since vehicles running red lights are usually not slowing down and in some cases speeding up, the probability of survival by a pedestrian struck by a vehicle in this case is very low. Again simple kinetics would verify this outcome. As a result, intersections with high pedestrian volumes and/or traffic volumes need to be closely examined.

Guideline 5, Intersection Degree of Saturation

With higher degrees of saturation at intersections the headway gaps between vehicles is smaller. Consequentially, there is a greater probability of vehicle running red light whether intentionally or unintentionally. The difference between these two intentions needs to be recognized and quantified. Errors in judgment are possible for drivers when approaching an intersection, it is generally agreed that violations, which occur greater than half a second after the onset of red are typically indicative of blatant disregard for clear-cut stopping conditions (23). The previous is only true if the yellow phase has been properly computed. In order to insure proper computation, the utilization of the ITE formulations is strongly recommended. Not only is entering the intersection after the onset of the red indication illegal and dangerous, it also reduces the green time (in effect) for the opposing traffic which reduces the capacity of the intersection. As this trend continues, the resulting domino effect creates gridlock and system malfunction.

Guideline 6, Perceived Benefit to Cost

As with all engineering countermeasures, the costs associated with the installation of a system should be evaluated. These costs do not only include the costs of construction and equipment, but also the

beneficial costs received from the reduction in crashes due to red light violators. In order for a red light enforcement system to be efficient, the resulting decrease in crashes and violations attributed to red light running and subsequent economic benefit from the reduction should be less than any other available policy (23). It is not necessary to determine the actual numerical effect at first, as this is highly improbable prior to installation. Rather by logical analysis, it can be discerned whether or not a part of a potential policy has a positive or negative benefit.

Guidelines Review

The review of the draft guidelines was completed by individuals who were involved with the original survey and some outside experts in the field. Table 4 shows the individuals involved in the review. The response of the individuals as a whole was positive. The changes put forth by the review committee included: further explanation of vague descriptors, addition of assumptions, language correction, and minor corrections.

Table 4: List of Review Committee

Reviewer	Location
Clement Gibson	Charlotte, NC
George Frangos	Columbia, Howard County, MD
Jennifer Kroening	Scottsdale, AZ
Kevin Bowser	Fairfax City, VA
Michael Cynecki	Phoenix, AZ
Michael Kinney	Montgomery County, MD
Natalie Dewberry	Santa Monica, CA
Scott Swenson	Oxnard, CA
Shawn Hawkins	Chandler, AZ
Shawn Turner	College Station, TX

CONCLUSIONS

In summary, the use of red light cameras has shown a generally consistent reduction in violations and crashes. As this technology is still rather new to the United States, further investigation and crash analysis is needed. Though from international programs the long-term reduction of crashes and violations have been documented. However, it should be stressed that red light cameras are one of the tools to combat the problem of red light running. They should be used as a last resort, and the installation of such systems signifies that traditional enforcement and other engineering countermeasures are not sufficient for solving the problem.

The overall theme of automated enforcement is to increase safety. However, opponents claim that the main goal of red light cameras is to create revenue. While this has been true in some past cases, the author believes that it is not true currently. Consequently, the engineering and law enforcement communities should continue to guard against such skewed practices. The goals of a red light camera system should be to:

- Reduce traffic crashes and dangerous driving,
- Save lives,
- Reduce health care costs,
- Increase police officer safety,
- Respond to public concerns, and
- Create violator-based revenue for increased public safety.

The main type of crash that is of concern is the right angle or “T-bone” crash. This crash results from a violation of a driver of a traffic control device. Red light cameras have proven effective in combating this particular type of crash. While, rear end crashes may increase upon the installation of a red light camera system due to panic stops or other factors, communities should not be discouraged from stopping their programs. Rear end crashes at intersections are generally not as serious in nature as right angle crashes, and may also result from other factors independent of the automated enforcement system. Some of these factors are insufficient headway, driver distraction or “multitasking”, congestion, and driver uncertainty coming up to a signalized intersection. The use of red light cameras should only be an extension of the current enforcement techniques already used.

RECOMMENDATIONS

There is a great need for further research in the area of automated enforcement and red light cameras. Currently, ITE and FHWA are working a Practitioners Guide that would include examination of the analysis or engineering process, which should be conducted prior to placing Red Light Cameras at an intersection (26). Additionally, a "Pocket Guide" for considering factors for the location and placement of Red Light Cameras is being developed. Eventually, the profession needs to decide whether or not to create a series of warrants, such as those available for signals. This would have to come after more research and studies tying the characteristics of intersections with red light running crashes. As stated previously, the main goal is to prevent and greatly reduce red light running in order to save lives.

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 sincerely thank his professional mentor, Mr. Wayne Shackelford of Gresham, Smith and Partners for his insight, expertise and encouragement. A special thanks is warranted to Dr. Conrad Dudek for his development of the program and the opportunity to be involved with outstanding professionals in the transportation field. The author would also like to extend his heartfelt appreciation to the other 2002 Mentors: Jack Kay, Walter Kraft, Gary Trietsch, Thomas Werner, and James Wright for their advice and devotion of time and expertise. Furthermore, the following transportation, law enforcement, and research professionals provided invaluable insight and knowledge that made this paper possible.

- Kevin Bowser, Photo Red Light Technician, Fairfax City Police Department, Fairfax City, VA;
- Michael Cynecki, Traffic Engineering Supervisor, Street Transportation Department, Phoenix, AZ;
- Officer Natalie Dewberry, Special Enforcement, Santa Monica Police Dept., Santa Monica, CA;
- John Di Lavore, Director, Red Light Camera Safety Program, New York City, NY;
- Clement Gibson, Special Programs Manager, CDOT-Park It! and SafeLight Programs, Charlotte, NC;
- Sergeant Shawn Hawkins, Traffic Unit, Chandler Police Department, Chandler, AZ;
- George Frangos, Traffic Engineer, Traffic Division, Columbia, Howard County, MD;
- Michael Kinney, Senior Engineer, Dept. of Public Works and Transportation, Montgomery Co., MD;
- Jennifer Kroening, Traffic Engineering Analyst, Transportation Systems Department, Scottsdale, AZ;
- Lt. Wayne Lorch, Phoenix Police Department, Phoenix, AZ;

- Senior Officer Scott Swenson, Oxnard Police Department, Oxnard, CA; and
- Shawn Turner, Assistant Research Engineer, Texas Transportation Institute, College Station, TX.

Finally, the author would like to thank his parents, Larry and Norma Hogue, who taught him that no goal is unreachable and always stressed the importance of hard work and a quality education. Thank you from the bottom of my heart.

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APPENDIX A: SURVEYS

Email

Dear Sir or Madam:

My name is Norman Hogue and I am graduate student in Civil Engineering at Texas A&M University. I am preparing a technical paper for the Advanced Surface Transportation Systems program in conjunction with the Southwest Region University Transportation Center. My paper is titled "Reducing Crashes Caused By Red Light Runners". My main goal is to determine whether the use of photo enforcement reduces the amount of collisions at intersections where it is installed. The stretch goal of this paper is to conduct a peer review of draft warrants that are being developed for the selection of a site for the installation of automated enforcement technology. I am conducting a short survey to synthesize the current criteria used in the installation of such systems. I would appreciate if you could take time to fill this survey out. Thank you for your time.



Survey.doc

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College Station, TX 77843-3135

Survey

Red light enforcement survey

By: Norman Hogue, Graduate Assistant Researcher, TTI

Advanced Surface Transportation Systems

- Does your department/ company have a set of criteria for choosing intersections for the installation of red light enforcement systems? If so, what are the criteria you use?

- If not, how do you choose one intersection over another?

- What are the traffic volumes at the intersections where the systems are installed?

- Has there been an evaluation of the effect of the red light enforcement systems on the crashes at the intersections where it is in use? If so, what types of crashes have decreased (i.e. right-angle, rear-end collisions)? Has there been an increase in any particular type of crashes?

- I will be conducting a peer review in mid July. Would you be willing to participate?

Follow-up Email

Dear Survey Participant:

First of all, I would like to express my sincere thanks for your input on my survey. I have compiled all of the results from each city/ county. From these results, I have created a list of guidelines for the site selection of an intersection for the installation of red light cameras. I have attached the guideline section of my paper, and would appreciate your feedback. Thank you again for your help and time. After the final submittal of the paper, I will be happy to share the findings with you.

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Draft Guidelines -
RLR.doc

Draft Guidelines – Red Light Running

Guidelines are a suggested set of instructions that *should* be used. They are developed using successful experiences with similar situations. Guidelines are used when a policy would be too limiting or confining, or for situations that are highly variable. They allow careful assessment of intersection conditions that are indicators for the need of traffic control devices or engineering countermeasures. The following guidelines, developed by the author of this paper, are intended for the site selection of intersections for the installation of photo enforcement systems. These are to be used along with the previous recommended stages for the implementation of red light running countermeasures. The implementation of these guidelines signifies that traditional enforcement and other engineering countermeasures are not sufficient for solving the problem.

Guideline 1, Accident History

Just like the presence of mold signifies the end of a products useful life, so the history of crashes signifies the presence of a problem with an intersection. The type of crashes that is most often tied to red light running is right angle crashes. These crashes often result in serious injuries or even deaths due to the fact that the side of the vehicle is the most vulnerable section. First of all, a traffic engineering study needs to be conducted in order to identify the extent, existence, and causes of the problem. The use of accident statistics can be helpful in this area, though the author disagrees with the total reliance on them alone. Accident statistics should be used to identify problem areas that need to be investigated further.

Guideline 2, Red Light Citation History

The evidence that there is a problem is a good indicator that countermeasures need to be implemented. Usually the presence of these citations is more of an indicator of allocation of available police resources and the relative safety of enforcing the law. Nevertheless, this is a red flag that should alert one to possible problem intersections though others may exist. Also to be included are areas when there is a high amount of complaints of red light running. A good approach to quantifying these complaints is through public meetings, where there is a dialogue between the citizens, police, and engineering communities.

Guideline 3, Approaching Speeds

From general kinetic principles we know that vehicles with greater speeds contain larger potential kinetic energy, which must be dissipated in order for the vehicle to stop. The problem arises when an approaching vehicle violates a traffic signal creating the potential for a crash. Also as the speed increases, the severity of resulting crashes increases as well. There may be situations where there are high approach speeds and high violations, but few crashes. These areas need to be further evaluated and closely monitored for possible development of crashes.

Guideline 4, Traffic and Pedestrian Volumes

Generally higher traffic volumes relate to a greater probability of violations and accidents. This is of particular concern when the cross-street traffic volumes are also high as well. While the crash of two vehicles can result in either injury or death, the same is not true of a vehicle-pedestrian collision. Intuitively, the pedestrian is almost always killed or severely injured when a vehicle runs a red light and collides with them. Since vehicles running red lights are usually not slowing down and in some cases speeding up, the probability of survival by a pedestrian stuck by a vehicle in this case is very low. Again simple kinetics would verify this outcome. As a result, intersections with high pedestrian volumes and/or traffic volumes need to be closely examined.

Guideline 5, Intersection Degree of Saturation

With higher degrees of saturations at intersections the headway gaps between vehicles is smaller. Consequentially, there is a greater probability of vehicle running red light whether intentionally or unintentionally. The difference between these two intentions needs to be recognized and quantified. Errors in judgment are possible for drivers when approaching an intersection, it is generally agreed that violations, which occur greater than half a second after the onset of red are typically indicative of blatant disregard for clear-cut stopping conditions. Not only is entering the intersection after the onset of the red indication illegal and dangerous, it also reduces the green time (in effect) for the opposing traffic which reduces the capacity of the intersection. As this trend continues, the resulting domino effect creates gridlock and system malfunction.

Guideline 6, Perceived Benefit to Cost

As with all engineering countermeasures, the costs associated with the installation of a system should be evaluated. These costs do not only include the costs of construction and equipment, but also the beneficial costs received from the reduction in crashes due to red light violators. In order for a red light enforcement system to be efficient, the resulting decrease in crashes attributed to red light running and subsequent economic benefit from the reduction should be less than any other available policy. It is not necessary to determine the actual numerical effect at first, as this is highly improbable prior to installation. Rather by logical analysis, it can be discerned whether or not a part of a potential policy has a positive or negative benefit.

NORMAN L. HOGUE



Norman Hogue earned his Bachelor of Science degree in Civil Engineering from Texas A&M University in August 2001. As an undergraduate, he spent four years as a member of the Texas A&M University Singing Cadets, where he was honored to perform for such distinguished people as former Presidents George W. Bush, Bill Clinton, Jimmy Carter and Gerald Ford, the Duchess of Derbyshire, Prince Harry and William, and many others. During the summer of 1999, he worked for the Texas Transportation Institute (TTI) on the needs of Older Drivers where he developed and conducted a survey for the creation of a driver refresher course.

Norman is currently pursuing a Master of Engineering degree in Civil Engineering at Texas A&M University. He is employed as a Graduate Research Assistant at TTI, where he works on the durability of retroreflective pavement markings and applications for advance sign sheeting materials. He is a member of Chi Epsilon National Civil Engineering Honor Society and the Texas A&M University Student Chapter of the Institute of Transportation Engineers where he currently serves as the Membership Secretary. Norman's career interests include traffic operations, traffic control devices, and highway design, construction, and maintenance.

STRATEGIES USED BY STATE DOT'S TO ACCELERATE HIGHWAY CONSTRUCTION PROJECTS

by

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SUMMARY

Everyday motorists are faced with driving through construction work zones throughout the state of Texas. Some construction projects due to their location and type of traffic control increase congestion and delays. There is a need to speed up construction on all types of projects using accelerated construction strategies. To determine the extent of accelerated construction strategies usage in the United States, the author conducted a State Department of Transportation (DOT) survey which includes a survey done by Dr. Stuart Anderson of TTI and contacts by the author for several districts in the state of Texas, Florida and New York DOT's. The results of the survey indicated that most states that responded are using accelerated construction strategies in some form or fashion, especially on large projects that impact the highway travel lanes.

Based on the research, the following techniques were determined to be applicable to address the problem of accelerating construction time:

- Calendar day definition for Working Day;
- Incentive Using Contract Administrative Cost;
- Milestones with Incentive/Disincentives (I/D);
- Substantial Completion I/D;
- Lane Rental Disincentive;
- A + B Provision;
- Variable Lead Time; and
- Design-Build

Each of the techniques was classified as levels of acceleration; however, the most widely used and most liked by DOTs and contractors as well, are the Incentive/Disincentive techniques. They are win-win situations for both parties and they result in shorter construction times and monetary gain to contractors. Several techniques were applied to example projects in the Atlanta District in order to test the guidelines developed from this report. The results indicated that depending on the type of projects, size and location of the project. There is always going to be an available technique that can be utilized to accelerate any type of construction project.

Guidelines for various levels of acceleration were developed from this report and the results of these guidelines appear to be applicable to all projects depending on the level of acceleration desired and warranted by a particular project.

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INTRODUCTION

Every day motorists are faced with driving through construction work zones on numerous highways throughout the State of Texas. Some construction projects due to their location and type of traffic control increase congestion and delays. Other smaller projects don't contribute to the delay, but their long duration causes the motorists to be aggravated due to the length of time that it takes for completion of the project; sometimes projects contribute to road rage or a bad image of the Texas Department of Transportation (TxDOT) due to their prolonged duration of construction.

Projects in smaller Districts range from the installation of traffic signals to the reconstruction of a five-lane highway through an urban area. Usually these types of projects have not had any special provisions to accelerate construction thus making them last a long time. For the most part, contractors are given more than enough working days needed to complete some of these projects. The motorists see that the contractors do not make much progress and often there is no construction taking place, thus they start complaining to the Department.

There is a need to develop a set of guidelines that will help all TxDOT districts to be able to determine what type of projects are better suitable for accelerated construction.

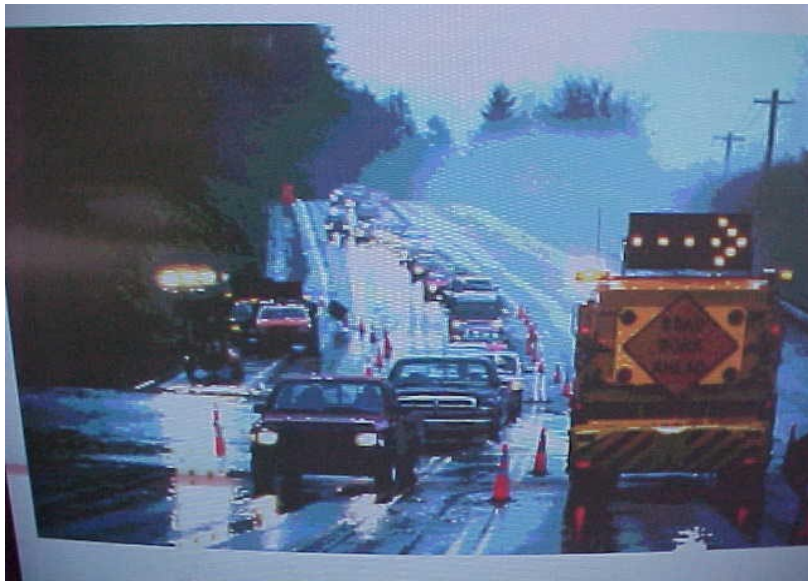


Figure 1. Workzone Congestion

Research Objectives

The overall goal of this research was to develop a procedure that can be used by TxDOT to accelerate construction projects. The specific objectives of this research are:

- Determine procedures other selected state transportation agencies are utilizing to accelerate construction projects of various sizes;
- Determine the positive and negative attributes other state agencies have experienced in accelerating construction projects;
- Determine procedures being implemented throughout the TxDOT to accelerate construction projects;

- Determine the obstacles to implement a procedure to accelerate small construction projects based on the experiences of TxDOT;
- Investigate the impacts to contractors caused by applying accelerated construction methods into the project;
- Develop a procedure that will be useful and effective in a smaller district such as the Atlanta District; and;
- Review these procedures in the Atlanta District and evaluate their effectiveness in smaller projects.

THE NEED FOR ACCELERATED CONSTRUCTION STRATEGIES

Recently, the Federal Highway Administration carried out a number of surveys of American citizens to understand what customers thought of their everyday roadway systems, and what they felt needed to be improved (1). The results are instructive not only at a national level, but for state and local officials as well as their appointed transportation executives.

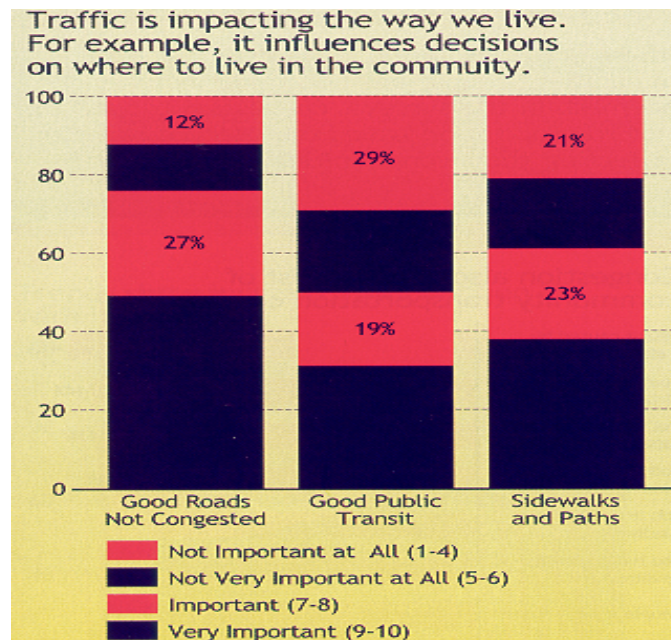


Figure 2. Traffic Impacts Survey Results

Sure, that two-hour backup on the expressway has always had a cost in time lost and irritated drivers – but now it reverberates to assembly lines that are forced to shut down, and retailers who lose sales because products have not arrived. In the eyes of an executive making a location decision, regional congestion adds up to higher operating costs, higher costs of living, and a lower quality of life for prospective recruits.

What Citizens Want

While citizens are concerned with congestion, they have matured in their response to what they want done about it. Improving both traffic flow and safety top their list of highway characteristics that should receive the most attention (See Figure 3) (1).

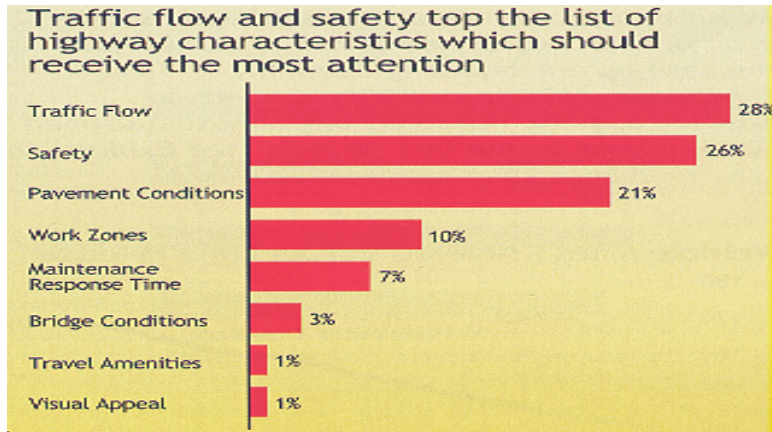


Figure 3. Traffic Characteristics (L)

Improving highway safety is a national priority. Almost 42,000 people each year still die on the highways. The survey results show safety is still a primary public concern. They also show that the public sees traffic accidents as a congestion issue – and rightly so. Twenty-seven percent responded that accidents are the main reason for traffic delay in their communities, compared to only 10 percent five years ago (See Figure 4) (L). Indeed, highway accidents and incidents consume as much as 1/3 of the roadway capacity during peak hours in U.S. metropolitan areas, and they are the primary culprits in system unreliability.

Citizens appear to be recognizing the ever-higher price tags associated with new capacity construction. Not only do they realize the expense in tax dollars, but in time. New capacity takes a long time to deliver – perhaps well beyond the time citizens might actually benefit from it! It also entails the double negative of seemingly endless traffic delays associated with construction zones and worse, the potential of having the new construction “in my backyard.”

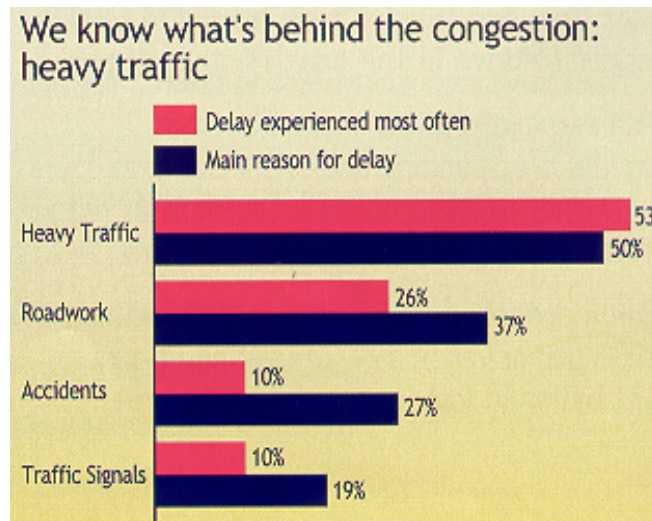


Figure 4. Traffic Issues (L)

When citizens were given a long list of possible solutions, and asked how much they thought each option would help, the top three responses suggested that we should do everything we can to minimize the pain of necessary maintenance and rehabilitation. Putting in more durable pavement, working in non-rush hours, and find ways to reduce repair time (See Figure 5) were the top preferred improvements. Next, there is a need to focus on better system operation with improved traffic signals and quicker response to accidents. Only then more travel lanes should be considered (Priority #6). A similar question as to how community transportation might be improved echoed the theme of making our existing system function better. Suggestions included providing more sidewalks and bikeways, and promoting greater use of public transportation.

The truth probably lies somewhere in between. While better operation of the existing system cannot “solve” congestion by magically turning bumper-to-bumper traffic into free-flow, there is solid evidence that aggressive, fully integrated, real-time, and full-time operations can make things a lot more livable. It can substantially improve traffic flow. It can reduce traffic delays. It can improve the reliability of the system. It can reduce the number of accidents and fatalities as well as the cost associated with responding to them. Perhaps, most important, it can restore a feeling of “control” to citizens as they try to cope with crowded roads.

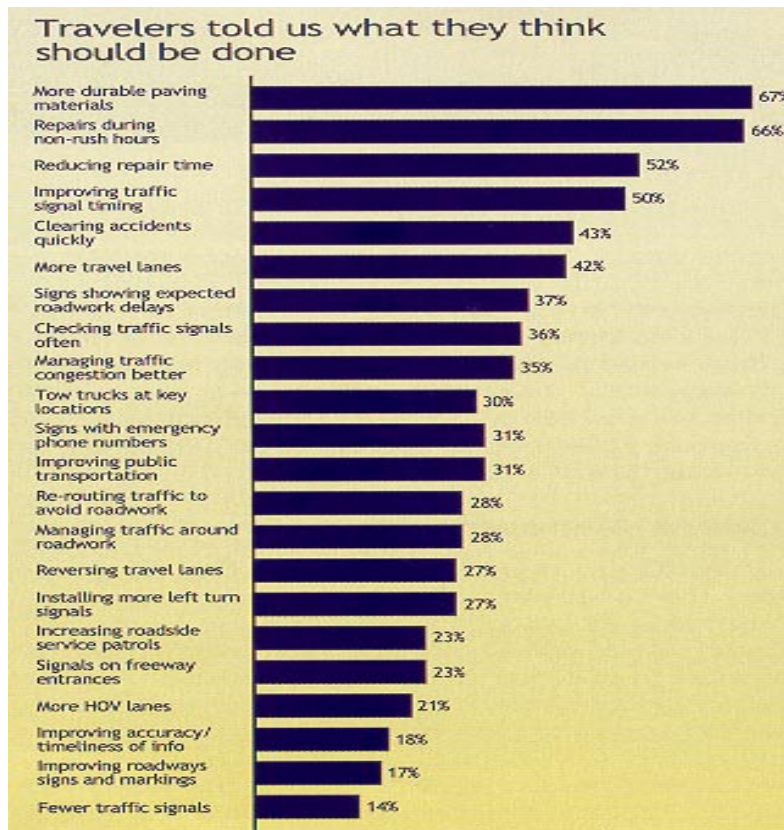


Figure 5. Travelers Survey (I)

Work Zones

Issues associated with work zones are cited as two of the top five complaints of travelers across the country. People are frustrated both by the number of work zones they encounter, and the delays that they cause. While there is not single solution, there are meaningful solutions that come from looking at the

issue holistically, beginning with project and program financing and continuing through the planning and construction phases. The key to minimizing the impact of construction and/or maintenance is to recognize the effect of the proposed work in sufficient time to develop and implement the appropriate cost-effective traffic management measures – prior to the delays occurring.

BACKGROUND

State highway agencies (SHAs) as most agencies and organizations, are experiencing pressure to improve cost, time and quality in project development and execution of facilities (9). At the same time, many agencies continue to downsize, restructure their organizations, and, as a consequence, reduce personnel. Some agencies have already downsized and are simply working with fewer personnel. Concurrently, outsourcing of project-related functions is being used to shift more responsibilities to design consulting and construction contracting communities. When SHAs shift project responsibilities through outsourcing, they naturally shift more project risks to other organizations.

In an effort address these issues, SHAs must be proactive in pursuing innovative practices when programming and executing projects. Innovations must be pursued in all areas of project programming and execution. One area where many agencies are encouraging innovation is construction contacting.

Comparison of Contracting Strategies for Reducing Project Construction Time

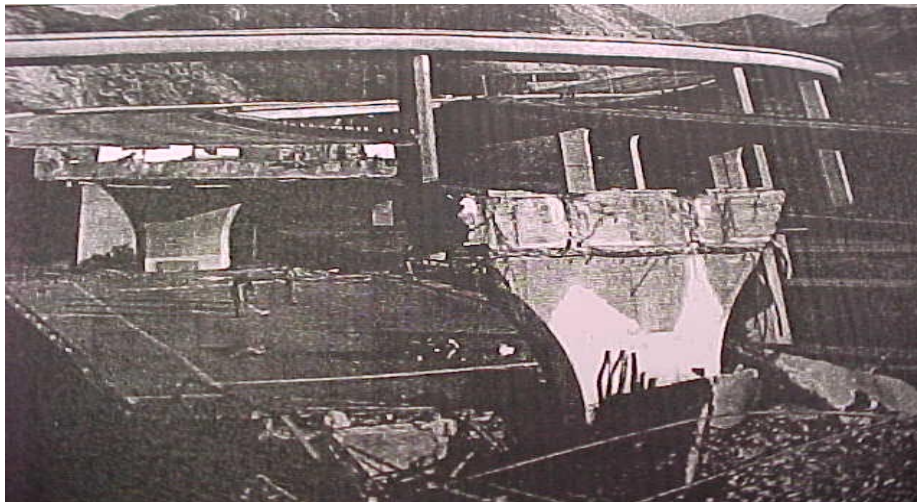


Figure 6. California's Santa Monica Freeway after the L. A. earthquake (2)

McFarland and TTI researchers Ray Krammes and Richard Kabat in 1994 evaluated the advantages and disadvantages of various types of incentives. “The purpose of the project was to look into the use on incentives with more detail. My own emphasis was to find out why incentive contracts weren’t being promoted, and to renew the transportation industry’s interest in them,” McFarland said.

TTI researchers concluded that incentive/disincentive procedures should not be used routinely in Texas, but should be reserved for specific situations. McFarland cited four cases in which special provisions or incentives should be used in Texas (2):

- In special cases of urgency,
- When projects have a relatively short time duration,
- When there is a clean set of plans, or
- When there is little chance of field changes.

“The ultimate objective of the research was to determine contracting strategies that would result in the least total cost to motorists during construction, McFarland said (2). “By selecting a blend of contract provisions tailored to a specific project, rather than having a blanket policy, the odds of getting on-time project completions are greatly improved.”

Another method that has been used in Texas to encourage timely project completion is a provision whereby contractors must meet a Critical Path Method (CPM) schedule. If the contractors fall behind schedule, he or she must submit a new schedule showing how he or she will catch up. Failure to do so results in withholding of progress payments.

However, McFarland’s research of contractors’ cost curves suggests that, in some situations, jobs may not be completed as rapidly without the bonus. For instance, if the contractor unexpectedly gets ahead of schedule, the procedure may be altered so that he doesn’t finish early. But, if the contractor knows the possibility of a bonus exists, he may complete the project early (2).

Innovative Contracting Strategies (3)

Cost-Plus-Time Bidding

Cost-plus-time bidding, more commonly referred to as A + B bidding involves contract time, with an associated cost, in determining the low bid. Under A + B bidding, each bid submitted consists of two parts. The “A” component is the traditional bid for the contract items and is the dollar amount for all work to be performed under the contract. The “B” component is a bid for the total number of calendar days required to complete the project, as estimated by the bidder. Calendar days should be used to avoid the potential for controversy that may arise if workdays are used

The lowest and best bid is based on a combination of the bid for the contract items and the associated cost of the contract time, according to the formula $A + (B \times \text{road user cost/day})$. The road user cost per day is determined by the contracting agency and is specified in the bid documents. This formula is used only to determine the lowest and best bid and not to determine payment to the contractor. The contractor is paid for the work performed (i.e., the items included in the A component). The final payment to the contractor is adjusted by any incentive or disincentive earned.

A disincentive provision must be incorporated into the contract to discourage the contractor from overrunning the contract time bid for the project. The daily disincentive amount should equal the daily road user cost used in the award determination. In addition, an incentive provision may be included in the contract to reward the contractor for completing the work in less than the bid time.

The A + B bidding concept is not appropriate for all projects. However, for critical projects that significantly affect road users, the A + B bidding concept can be an effective technique to greatly reduce such interference.

Lane Rental (3)

As with cost-plus-time bidding, the goal of the lane rental is to encourage contractors to decrease the effects on road users during construction. Under the lane rental concept, a provision for a rental fee assessment is included in the contract. The fee is based on the estimated cost of delay or inconvenience to

the road user during the rental period. It is assessed for the time that the contractor actually occupies or obstructs all or part of the roadway. The assessed fees are deducted from the progress payments.

The rental fee amount is stated in the bidding proposal, but neither the contractor nor the contracting agency gives an indication of the anticipated amount of time for which the assessment will apply. The low bid is determined solely on the basis of the lowest amount bid for the contract items. The rental fee depends on the number and type of lanes (e.g., through lane, turn lane, ramp, shoulder) or combination of lanes closed. It can vary for different hours of the day (e.g., a higher rate may be charged during peak traffic hours and a lower rate during the off-peak evening hours).

The intent of the lane rental concept is to encourage contractors to schedule their work so that traffic impacts are kept to a minimum, in terms of both duration and number of lane closures. This concept has merit for use on projects that significantly affect the traveling public.

Design/Build Contracting (3)

The design/build concept gives the contractor maximum flexibility for innovation in the selection of design, materials, and construction methods. Under this concept, the contracting agency specifies the end result and establishes the minimum design criteria. The prospective bidders then develop design proposals that best use their construction abilities. The submitted proposals are rated by the contracting agency on the basis of design quality, timeliness, management capability of the bidder, and cost. By allowing contractors to optimize their work force, equipment, and scheduling, the design/build concept opens up a new degree of flexibility for innovation. However, along with the increased flexibility, the contractor must assume greater responsibility. An extended liability insurance or warranty clause should be used to ensure that the finished product performs as required.

From the perspective of a SHA, the potential time savings is the biggest benefit. Because both the design and construction are performed through? Procurement, construction can begin before all the design details are made final (e.g., pile driving could begin while a bridge lighting was still being designed). Both design and construction are performed under the same contract, claims for design errors or delays due to redesign are not allowed, and the potential for other types of claims is greatly reduced.

In 1990, the Federal Highway Administration initiated Special Experimental Project 14 (SEP 14), "Innovative Contracting Practices" considered to be innovative to the U. S. highway industry. In addition, SEP 14 is the vehicle through which the findings and recommendation of the Transportation Research Board Task Force on Innovative Contracting Practices are being validated.

FHWA has reviewed the design/build concept for compatibility with current federal laws and regulations. It has been determined that the design/build concept may be evaluated on federal-aid projects on an experimental basis under SEP 14, provided that contracts are awarded using competitive bidding procedures. The design/build concept should be applied only to those projects for which the end product or facility can be well defined.

Incentive/Disincentive Guidelines (4)

I/D contracts do not come without a price. The I/D provisions require increased administration to determine when project targets have been reached. It is important that close attention be paid to the construction process of an I/D contract. As discussed in *Contract Time Determination* ("Contract" 1981), the I/D provisions may result in increased claims by the contractor and increased pressure from outside organizations, such as the press, that the amount of the bonus may not be warranted.

This raises the issue of how to determine the I/D amounts that should be used in developing a contract. This is a rather difficult question, as each individual contracting situation is unique and must be treated as

such. It is generally agreed that the I/D amount must be based on the implicit costs discussed earlier; safety of the users; loss of user time due to traffic; the increase in gasoline consumption; and the increased administrative and monitoring costs associated with the use of an I/D contract. Monetary losses incurred by adjacent commercial enterprises should not be used to determine the I/D amount; however, it should be used to determine if a project warrants the use of an I/D project.

It must be noted that the courts have refused to enforce a penalty contract clause in the absence of a corresponding bonus clause. Liquidated damages may be assessed only if they represent the anticipated losses to the owner at the time the contract is signed.

Additional questions arise as to the form that the I/D provisions should take. There are various forms of the I/D contract that can be considered for any particular project. These forms consist of a bonus/penalty plan, a bonus-only plan, a penalty- (or liquidated damages-) only plan, a lane-rental plan, and nonmonetary incentives. The literature on the various forms of I/D provisions provides no definite answers to the question of which form of I/D provision is the most effective. However, Christiansen (1987) reports that nonmonetary I/D plans do not attain the same degree of success as monetary plans.

According to Finchum (1972), there are two different types of cost-based contract incentives; fixed-price firm incentives and cost-plus incentive fee. A fixed-price incentive firm plan provides the contractor with both a base payment and incentive/disincentive amounts. The I/D amount is based on a percentage of the target fee, which represents a fair profit for work that comes in at the target cost. Thus, if the project comes in below cost, a percentage of the savings gained by the agency that awards the contract as a result of the performance of the contractor is passed in the form of an incentive payment. If the contractor's performance results in an overrun on the contract cost, then he or she will be assessed disincentive amount equal to the incentive rate, as outlined in the contract. A cost ceiling is included in the incentive/disincentive plan, which represents the maximum liability of the contractor should a disincentive be assessed.

Initial Consideration (4)

The goal of the contracting agency in any particular project is to complete a given project successfully within a specified time period and meet various requirements such as quality and cost levels. On each specific project, the various goals of cost, quality, and time span carry different levels of importance, with all having some minimum level of requirement. The success of any project depends on the degree to which all goals have been met.

Because each project has a unique set of goals, the I/D plan provides a way for the contracting agency to specifically determine the goals of the project and communicate those goals to the contractor. To implement an I/D contract successfully, several areas that are listed below must be addressed.

1. How can one determine which projects warrant the I/D contracts?
2. How should the cost of the I/D provisions be determined so that the goals of the contracting agency are met and the contractor is properly motivated?
3. How can the success and effectiveness of the I/D contract be measured?
4. How can additional and/or unforeseen problems be addressed within the I/D contract to ensure its success?
5. How should the magnitude of I/D be determined such that it can affect time compression?
6. Can nonmonetary rewards be used to align contractors' goals to those of the contracting agency?
7. Can a combination of monetary and nonmonetary considerations be used to develop the I/D provisions?

These are all areas of concerns for the agency issuing the contract and need to be discussed and resolved.

Determining I/D Dollar Amounts (4)

The way in which the I/D amount is determined and documented is very important to the contracting agency. If the contracting agency becomes involved in a legal dispute with the contractor concerning the use of I/D provisions, and the I/D amount has not been well developed and documented, then the contracting agency may very well lose in a court case.

In addition to the I/D amount, each state-contracting agency must determine what is the maximum I/D payment they are willing to make. The federal government will pay the same portion of the incentive payment as it pays for the regular construction. FHWA recommends a cap of 5 percent of the total project cost be used as the maximum incentive ("Incentive/Disincentive" 1989). In addition, with experience, states may feel comfortable in not setting a limit on the number of days for which an incentive can be earned.

Schedule and Delivery Incentives (5)

Schedule incentives have traditionally been those of threats or penalties. An example is the traditional liquidated damage clause. A schedule incentive describes the premium paid to the contractor whenever the deliver is made earlier than a target date. This premium often becomes negative once the target date has been passed. Delivery incentives require that an agreed firm program is in place, if they are to be negotiated concurrently with the cost incentives of the contract (Ashley and Workman 1986; Blyth 1969).

Performance or Technical Incentives (5)

Technical incentives are those tied to performance measures, other than cost and schedule. Typical measures include quality and safety. They may, however, cover any area of performance that a client wants to enhance. The basic principle is the same as with cost incentives. The contractor is offered a reward of additional profit if he achieves one or more specified levels of performance related to one or more performance elements of the specification (Blyth 1969; Ashley and Workman 1986).

Multiple Incentive Contracts (5)

In a multiple incentive contract, the incentives should be balanced to reflect the client's priorities. A multiple incentive arrangement should not only encourage the contractor to strive for outstanding results in all incentive areas, but, if during the course of the contract he realizes that he will not be able to achieve this, he is encouraged to take a trade-off decision, which is in the best interest of the customer. Combined incentives have proven complicated to administer but fairly successful (Blyth 1969; CII 1995).

Interrelationship of Construction Cost, Tender Price & Construction Time (6)

Construction Cost and time for undertaking a particular construction project are interrelated. Standard literatures on construction project scheduling [e.g., Callahan et al. (1994)] show that, to a particular construction company, for every construction contract there is an optimum cost-time point. At this point, the contractor would have the lowest construction cost. In general, the interrelationship between cost and time for a construction project is expressed in a curve as shown in Figure 7 (Cusack 1991). On this curve, the "normal point" represents the construction plan where construction cost (normal cost) is the lowest with a specific construction time (normal time). Any variation in time from the normal point will result in a corresponding increase in construction cost. For example, to shorten construction time will increase project direct cost due to the use of multiple shifts, overtime work, or other costly measures. Crowded work crews or excessive plant on site will make job supervision more difficult and is likely to result in lower work productivity. Material delivery in a shorter time is normally more expensive. On the other hand, an increase in the construction duration from the normal point will obviously incur the increase in general indirect cost.

Clough and Sears (1991) pointed out that the degree of cost increase toward the left side of the normal time point is much higher than that toward the right side. In other words, taking the normal point as reference, the impact of time reduction on cost increase is much larger than that of time extension. To expedite a project is often called “crashing.” The minimum time to which the construction of a project can be reduced is called “project crash time” and the construction cost corresponding to the project crash time can be called “project crash cost” (Clough and Sears 1991). However, as the relationship between construction cost and time is determined by many factors such as the contractors’ management skills and construction techniques, the shape of the cost-time curve will be different to the various contractors for a specific project. Therefore, for a particular project, different contractors will have their own “normal points” by which they can have their own lowest construction costs and “normal time.”

Furthermore, a contractor’s tender price for a contract is actually closely related to his construction cost, and such a relation can be written in the following formula (6):

$$\text{Equation 1} \quad p = c(1 + \infty)$$

where p = tender price; c = estimation of construction cost that has the relation with construction time shown in Figure 6; and ∞ = mark-up coefficient applied by the contractor. The parameter ∞ reflects the

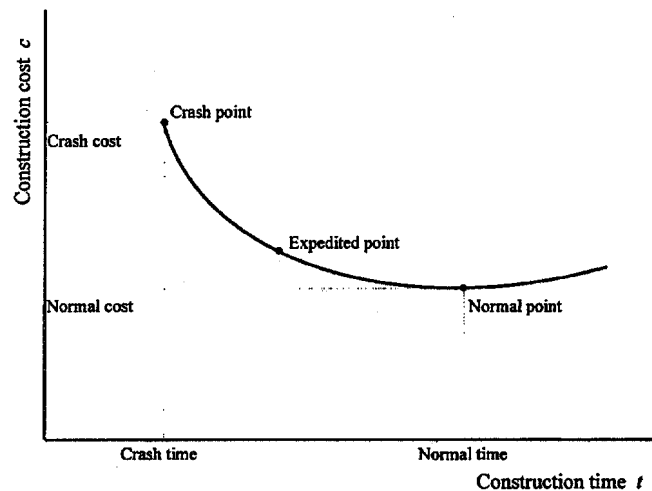


Figure 7. Interrelationship of Construction Time and Cost (6)

contractor’s demand on profit and premiums on uncertainties. Therefore, the contractor’s tender price is also closely related to construction time, and such a relation can be denoted with the following equation (6):

$$\text{Equation 2} \quad p = f(t)$$

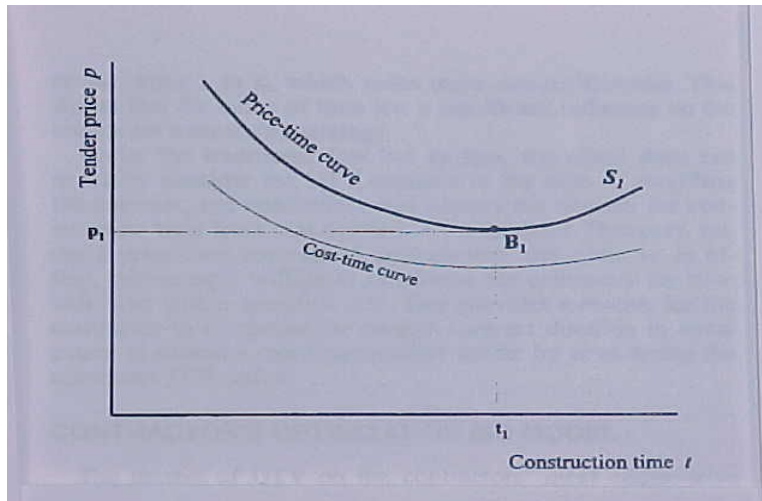


Figure 8. Interrelationship of Construction Time and Tender Price (6)

where p = tender price; t = construction time; and f represents a certain function relation between p and t . Equation (2) can be demonstrated by curve S_1 shown in Figure 8. The shape of the price-time curve is similar to the cost-time curve shown in Figure 6 as there is a constant coefficient $(1 + \infty)$ in (3) between construction cost and tender price, the price curve S_1 in Figure 8 is produced by proportionally shifting the cost curve upward.

It can be seen from the price-time curve S_1 in Figure 8 that point B_1 indicates a contractor's lowest tender price p_1 that could be offered with construction time t_1 . Under the traditional low bid system, in which the price is the major determinant, the contractor's most competitive strategy is to offer price p_1 with contract time t_1 in the case shown in Figure 8, provided that t_1 is shorter than the time specified in the contract.

Other Contract Strategies for Accelerated Completion & Tools for Minimizing Construction Time (Z)

- Calendar Day (CD) Definition for Working Day – Use alone with standard contract administrative liquidated damages (CALD) with time calculated to the final acceptance date. A five-day per week definition for working day is recommended for most applications. Calendar day definition for working day is required with all acceleration strategies.
- Use a 30, 60, 90, 120-day or other lead-time start date special provision in conjunction with acceleration provisions. The lead-time will allow the contractor to fully ramp up before work begins in the ROW. The lead-time provisions may be modified to address lead-time allowances for work in the ROW but off the roadway when said work does not create travel delay (Z).
- Work with local communities to make use of total intersection or road closure for isolated construction locations. Use milestones, calendar day definition for working day and I/D.
- Use nighttime work in urban areas and cities to reduce congestion for pavement operations. Consider construction noise, material delivery and traffic and worker safety in the decision.
- Use good sign management. Display signs only when needed. Place barricades just before work in the ROW is to begin. Place work zone speed limit signs only when speed reduction is needed. Use reasonable speed reduction (i.e., no more than 10 mph below the regulatory speed) during construction and therefore, provide for reasonable construction speed zones in design (Z). Remove construction barricades when the only work remaining is vegetation and plant establishment and performance periods.

- Consider removal of barricades when time is suspended in the winter for final surface placement and all other work is substantially complete, a durable full width safe pavement surface is provided, permanent markings and final safety work are complete and the only work remaining is the final surface. Utilize a full barricade setup when the final pavement work is performed the following season.
- Maintenance projects should include standard CALD for work that is time dependent. Consider using lane rental provisions in high traffic areas when working on the pavement or lane closures are required.

Value of Time and Road User Costs

Following on Table 1 is the consumer price index (CPI) as it stands in December 2001 by TxDOT in determining the value of time used in calculations of road user costs.

Comparison of the Value of Time Used by Various States (8)

In an effort to establish a comparison of the value of time used by various states, Texas Transportation Institute published in December 1999 a report entitled, “Techniques for Manually Estimating Road User Costs Associated with Construction Projects”. Below is a table that shows the comparison:

Table 1. Value of Time, 1985 – January 2001 (8)

YEAR	CPI	VALUE OF TIME	
		Drivers	1.25 Passengers/Vehicle
1985	322.2	\$8.08	\$10.04
1986	238.4	\$8.24	\$10.30
1987	240.4	\$8.48	\$10.60
1988	118.2	\$8.82	\$11.03
1989	124.0	\$9.26	\$11.58
1990	130.7	\$9.76	\$12.20
1991	136.2	\$10.17	\$12.71
1992	140.3	\$10.47	\$13.09
1993	144.5	\$10.78	\$13.48
1994	148.2	\$11.06	\$13.83
1995	152.4	\$11.37	\$14.22
1996	156.9	\$11.71	\$14.64
Jun – 1997	159.9	\$11.94	\$14.92
Jan – 2000	168.3	\$12.56	\$15.70
Jan – 2001	174.0	\$12.99	\$16.24

Table 2. Comparison of Value of Time (8)

State	Value of Time Automobiles	Value of Time Trucks
North Carolina	\$8.70	-0-
New York	9.00	21.14
Florida	11.12	22.36
Georgia	11.65	-0-
TEXAS	11.97	21.87
Virginia	11.97	21.87
California	12.10	30.00
Pennsylvania	12.21	24.18
Washington	12.51	50.00
Ohio	12.60	26.40
Median	\$11.97	\$23.61
Mean	\$11.38	\$27.23

**SURVEY OF THE USE OF ACCELERATED CONSTRUCTION STRATEGIES
IN THE UNITED STATES**

Current Status of Multi-Parameter Bidding in the United States

Through the literature review, the author located a recent survey done by Stuart Anderson of the Texas Transportation Institute of all 50 states with respect to accelerated construction strategies. The survey conducted in 1999 reflects the latest construction strategies being utilized by all states in the U. S. (See Table 3)

Table 3. Current status of Multi-Parameter bidding in the United States (9)

States (1)	Used A+ B (2)	State Funded/Federally Funded (3)	Other Parameters (4)	Number of Projects (5)	Estimated Cost (6)
Alabama	yes	both	None	2-3	\$100,000 each
Alaska	no	---	---	---	---
Arizona	no	---	---	---	---
Arkansas	yes	FA	lane rental	21	111 M
California	yes	both	I/D	10-12	---
Colorado	yes	both	none	4-5	5-10 M range
Connecticut	no	---	---	---	---
Delaware	no	---	---	---	---
District of Columbia	yes	FA	none	5	\$25-40 M range
Florida	yes	both	I/D	3-4	\$3-19 M range
Georgia	yes	both	none	6	\$3-4 M range
Hawaii	no	---	---	---	---
Idaho	yes	both	I/D	7	\$22 M

Table 3 Continued

States (1)	Used A+ B (2)	State Funded/Federally Funded (3)	Other Parameters (4)	Number of Projects (5)	Estimated Cost (6)
Illinois	yes	FA	I/D	2	\$5 M
Indiana	yes	both	I/D + quality	8	\$70 M
Iowa	yes	FA	I/D	1	\$8 M
Kansas	yes	SF	none	1	\$10 M
Kentucky	yes	FA	none	2	\$10-23 M range
Louisiana	no	---	---	---	---
Maine	yes	both	I/D + lane rental	1	\$3 M
Maryland	yes	FA	none	10	\$5 M average
Massachusetts	no	---	---	---	---
Michigan	yes	FA	none	40-50	\$1-30 M range
Minnesota	yes	both	I/D	3	\$1-20 M range
Mississippi	yes	FA	none	2	\$8-10 M range
Missouri	yes	both	none	8	Multi M
Montana	no	---	---	---	---
Nebraska	yes	both	none	1	\$16 M
Nevada	yes	State funded	none	2-3	\$140,000 total
New Hampshire	no	---	---	---	---
New Jersey	yes	FA	none	25	\$2-5 M range
New Mexico	yes	FA	none	3	\$40 M
New York	yes	both	I/D	45	\$3-30 M range
North Carolina	yes	both	none	15	\$10-25 M range
North Dakota	yes	FA	I/D	1	\$5 M
Ohio	yes	both	none	15	\$35 total
Oklahoma	yes	both	none	10	\$6 M average
Oregon	yes	both	none	100	\$25 M
Pennsylvania	yes	FA	I/S	10	\$.5-15 M range
Puerto Rico	no	---	---	---	---
Rhode Island	no	---	---	---	---
South Carolina	yes	both	none	100+	\$.25-10 M range
South Dakota	yes	both	I/D	4	\$12 M
Tennessee	yes	both	I/D	3	\$2.5 M
Texas	yes	Both	See Texas Summary	See Texas Summary	\$114 M
Utah	yes	---	I/D	10	\$.5-15 M range
Vermont	yes	FA	None	1	\$3-4 M range
Virginia	Yes	Both	Lane rental	2	\$5-10 M range
Washington	No	---	---	---	---
West Virginia	No	---	---	---	---
Wisconsin	Yes	FA	None	4	Several M each
Wyoming	no	---	---	---	---

The author conducted a survey of various DOT's in order to verify and obtain more up-to-date information. Also a survey was conducted throughout the state of Texas Department of Transportation in order to determine the type of accelerated construction strategies currently being implemented. The results of the surveys were as follows:

New York State DOT

Statistics of A + B Bidding

Experience has shown that A + B bidding is an effective way to reduce construction induced congestion and delays by allowing the cost of work and time to be balanced through the open competitive bidding process. Contractors bid on average 32% below the Department’s estimated time and complete the work ahead of schedule.

A Summary of A + B bidding and performance results in New York State is shown below:

- 120 contracts completed “B” portion work. Approximate original contract value of these contracts is \$2.0 billion.
- 90 of the 120 contracts were awarded to the low “A” portion bidder. i.e., Bidder with lowest A + B total also had the lowest “A” portion contract amount. The other 30 contracts were awarded to a bidder with a higher “A” cost and a shorter “B” duration. Added “A” cost of these 30 contracts is less than 1%.
- 103 Contractors earned incentives. Total incentives paid = \$49,069,174. Total incentives paid are approximately 2.5% of original contract value for these 103 contracts.
- 9 Contractors completed on time. No incentives or disincentives.
- 8 Contractors accessed disincentive. Total disincentives = \$592,000.
- 59 contracts (50% of completed contracts) required B time adjustments.
- Estimated user cost savings for completed contracts = \$246 million.
- Estimated construction days saved = 20,000.

Florida DOT

Statistics of Incentive/Disincentive

The Florida DOT has completed 17 Incentive-Disincentive projects in the last 4 years. Of these 9 were completed early enough for the contractor to collect substantial incentive amounts. Please see following Table 4 for Florida’s Incentive-Disincentive projects.

Table 4. Florida’s Incentive Disincentive Projects

Contract Number	Original Contract Days	Days Used	Original Contract Amount	Incentive Disincentive Adjustments
19798	225	287	\$8,136,081.73	
19800	150	115	\$564,473.21	\$50,000.00
19835	200	369	\$2,990,871.99	-
19846	355	541	\$1,665,934.15	-
19852	140	149	\$1,352,475.88	
18887	245	297	\$3,436,780.29	\$162,000.00
19997	750	693	\$16,555,165.03	\$730,000.00
20027	80	105	\$1,381,034.63	
20102	140	116	\$332,112.44	\$18,000.00
20144	120	89	\$272,932.20	\$10,000.00
20161	465	346	\$7,248,326.32	\$380,000.00
20175	150	312	\$3,124,141.25	-
20313	375	261	\$1,887,286.55	\$300,000.00
20548	120	249	\$3,138,185.09	-
20653	170	163	\$1,355,000.00	\$35,000.00
20804	290	230	\$993,875.48	\$75,000.00
20924	100	122	\$628,117.59	\$(4,000.00)

Lessons Learned

Contract packages must be carefully put together so that there are no errors or internal inconsistencies that might invalidate the benefits of the use of incentive/disincentive. Care must be exercised in the administration of the project. Adding additional work must be done in such a manner as to have no impact on the Incentive/Disincentive dates.

Texas DOT

Table 5. Strategies Used in Texas

Strategies Used
5 – day Calendar Day
6 – day Calendar Day
7 – day Calendar Day
Contract Administrative LD Incentive for completion of project
Milestone for substantial project completion, Incentive/Disincentive based on Road User Cost
Lane Rental
Lane Rental Milestones
A + B Bidding Milestones
Lane Rental and A + B Bidding Milestones

Texas Construction Engineers Surveys

Houston District

Construction Engineer and Area Engineers agree that all preparation work is what determines success of accelerated construction strategies. A good construction timetable during design should consider contractor resources, work hours required, traffic control situations and closures required for items of work. A good set of plans is needed because you will not have time to resolve major conflicts and not much time for the minor ones either. Accelerated strategies are not good when you have outstanding right of way issues and utility problems because these types of problems will kill any time you hope to gain by acceleration; therefore, make sure that if you have these types of issues do not try to accelerate the project or at least being willing to pay for it.

- For the most part, all projects with accelerated construction strategies have been successful. They had a situation with a project A + B bidding and 6 calendar day definition and the contractor did not want to work on Sundays due to being charged for the 7th day; he wanted to make all incentives.
- Houston District has used A + B, lane rental, calendar days, incentive/disincentive, but they agree that the most beneficial has been the contractor incentives. Projects have been i.e., \$10,000/day and maximum incentive of \$420,200.
- Do not use incentives in small projects. High volume type projects are more suitable for acceleration. However, the District has used delayed start dates and deadline completion dates for small projects.
- They feel that all contractors have responded in a favorable manner and are accepting these types of projects better.

Dallas District

Construction Engineer has parallel views to Houston Engineers. The most recent project labeled “High Five” in Dallas has A + B bidding no-fault incentive of \$32,000/day with \$22.00 a minute for early completion up to 1 year \$11 million; \$260 million project cost.

- Nearly all projects in the Dallas District have been changed to calendar day (5, 6, 7-day definition).
- Windowed milestones are now considered on certain projects coupled with incentive/disincentives.
- Dallas District has been instrumental in the development of maturity testing for concrete strengths. This non-destructive test method allows for instantaneous in-place strength results (II).

Pharr District

Construction Engineer agrees that incentive/disincentives should be used to meet critical milestones justified by road user costs or long term delay to the motorists.

- All projects have been successful
- Queen Isabella is the most recent and prominent project using accelerated strategies. 7-calendar day definition with incentive/disincentive provisions. Incentive of \$10,000/day for 20 days maximum of \$200,000. Later added incentive of \$75,000/day for a maximum of 7 days and \$525,000. Total incentive paid to contractor was \$725,000.
- Pharr District is using calendar days for selected smaller projects.

Atlanta District

Construction Engineer suggests use of accelerated strategies on projects with higher road user cost.

- Most recent projects have been successful
- Have used incentive/disincentive strategies on larger projects that impact traffic flow on a selected basis.
- Atlanta District is using calendar days for selected smaller projects such as bridge reconstruction. Table 5 shows a complete summary of acceleration strategies that have been used in Texas.

Summary of Accelerated Construction Projects in Texas

Table 6. Summary of Accelerated Construction Projects in Texas

District	Total Projects 6/01-5/02	5 Days	6 Days	7 Days	Liquidated Damages Entire	Liquidated Damages per mile	Incen Entire	Incen per mile
Abilene	8	2	1				\$161,000.00	\$51,000.00
Amarillo	9	3	1					
Atlanta	17	2	2					
Austin	21	1						
Beaumont	6		1					
Brownwood	4	1	1					
Bryan	20	3						
Childress	2							
Corpus Christi	3		1					
Dallas	22	10	3					
El Paso	6	2	1					
Fort Worth	29	17						
Houston	32	1	7	5	\$22,500.00	\$258,333.33	\$22,500.00	\$477,500.00
Laredo	7	1	2					
Lubbock	4	2			\$6,000.00		\$6,000.00	
Lufkin	10	7						
Odessa	6							
Paris	10				\$4,250.00		\$4,250.00	
Pharr	8	5						
San Angelo	6		1		\$1,200.00		\$2,000.00	
San Antonio	12	4	1					
Tyler	12	2	1	2	\$4,200.00			
Waco	6	5						
Wichita Falls	9	5	1		\$5,025.00		\$443,080.00	
Yoakum	10	2						

Table 6 Continued

District	Lane Rental	A + B	Average Construction Cost	Freeway Road Closure	Bridge Closure	Road Closure	Additional Capacity Projects	One Free Lane Closure
Abilene			\$5,375,154.75	4	1		1	
Amarillo			\$7,634,283.33	1				
Atlanta			\$2,499,212.87	1				
Austin			\$2,679,462.81	2		1		1
Beaumont			\$1,506,293.20					
Brownwood			\$3,038,456.88	1				1
Bryan			\$1,402,400.28		1		2	1
Childress			\$2,202,992.37					
Corpus Christi			\$18,074,806.04			1		2
Dallas			\$1,918,900.38	2	1	1	3	1
El Paso			\$6,839,061.68			1		2
Fort Worth			\$2,147,484.78	3	7	3	3	4
Houston			\$6,930,059.08	6	1	1	5	3
Laredo			\$3,784,352.86	1			1	
Lubbock			\$5,969,965.49	1	1	1		
Lufkin			\$4,293,908.50					2
Odessa			\$675,367.93	2				
Paris			\$3,277,543.36	1	1	1	1	
Pharr			\$4,317,793.84		2	2	2	
San Angelo			\$6,852,309.20				2	1
San Antonio			\$5,512,843.29	4	3	5	1	1
Tyler		1	\$3,504,768.17	1	3			3
Waco			\$8,812,547.39				3	2
Wichita Falls			\$3,448,265.79		2	1		2
Yoakum			\$3,590,120.15	1	2	1		1

FHWA Perspective*Work Zone Study*

The author contacted the FHWA workzone study group to determine what the latest efforts are and the FHWA perspective in regards to accelerated strategies. FHWA's Office of Program Quality Coordination conducted a quality improvement review entitled Meeting the Customer's Needs for Mobility and Safety During Construction and Maintenance Operations between December 1997 and June 1998 (10). The purpose of this quality improvement review was to assess the effectiveness of FHWA and State DOT policies and procedures in enhancing safety, improving mobility, and increasing the efficiency of the National Highway System (NHS) by reducing traffic congestion/delays during construction and maintenance operations. The results of this study include a description of the state of practice in work zones, identification of items that should be pursued to achieve state of the art in reducing motorist delays and enhancing safety in work zones, and a listing of best practices for improving work zone mobility and safety (See Figure 9). This report has served as a guiding document to FHWA's Work Zone Mobility and Safety Product Team.

4. Contractor has received some good publicity on the projects noted above. It is appreciated but the good PR benefits the entire highway program. This means more to us than the corporate recognition.
5. Contractor has the opinion that smaller projects are not suitable for acceleration techniques other than maybe calendar days will increase the cost of construction. To truly accelerate a project, there has to be a financial reward. If TxDOT simply reduces the amount of time allowed, the cost of construction will increase because of the demands on resources. Increased demand on resources means that the contractor cannot necessarily operate as efficiently as possible thus increasing his construction cost.
6. Accelerated techniques must be used judiciously. Overuse will unnecessarily inflate the cost of construction. There are human impacts that should be given consideration as well.

Requirements of the 75th Legislative Session in Texas

During 1998 SB 370 passed during the 75th Legislative Session requires the Texas Department of Transportation to conduct a review of certain rules and laws. The intent of the amendment was to look at ways of building and maintaining highways faster and at a reduced expense. Specifically, the statutory language is as follows:

Transportation Code, Section 223.012. CONTRACTOR PERFORMANCE

(a) The department shall...

(3) conduct a review to determine whether commission rules or state law should be change to realize significant cost and time savings on state highway construction and maintenance projects.

(b) Not later than December 1, 1998, the department shall file a report with the governor, the lieutenant governor, and the speaker of the house of representatives containing:

(1) the result of the review conducted under Subsection (a)(3); and

(2) recommendations on legislation the commission determines is necessary to realize significant cost and time savings on state highway construction and maintenance.

The Department's Executive Director responded to this directive by forming a working group consisting of:

Gary K. Trietsch, P.E., Houston District Engineer;
 Robert L. Wilson, P.E., Design Division Director; and
 Thomas R. Bohuslav, P.E., Construction Division Director

The group was charged with ensuring that the department completed the task of reviewing Texas Transportation Commission rules and state law. They worked in conjunction with the Commission, and the Department's Administration, Legislative Affairs Office and Office of General Counsel to identify, develop and refine the issues which are discussed in this report.

The Department viewed this report as an opportunity to discuss recent internal initiatives, as well as provide thoughtful options to the Legislature which may have a positive influence on the agency's future operations. It was noted that recommendations resulting from this effort must be pursuable at the state legislative level. While a strict reading of the report's requirements could be seen as limiting its scope to addressing recommendations that would have effect once a construction or maintenance project begins, the department also addressed project development issues in line with what it believes to be legislative intent.

In Mr. John W. Johnson's (highway commissioner) Working Group Report of August 22, 2001, "Texas Transportation Partnerships...Connecting You to the World," the section on Streamlined Project Delivery

established a goal of improved project delivery from conception to ribbon cutting on average, by 15 percent within 5 years. The goal was presented in the context of the cost of disruptions to traffic flow. Because of increased traffic and congestion we must heighten our attention to time requirements for projects and demand contractor's uninterrupted prosecution of the work. The public, legislature and the Commission have asked us to implement strategies to reduce construction time beyond previous guidance. We are therefore revising the previous guidance to now require acceleration provisions for projects that disrupt traffic. The requirement will apply to projects beginning with the May 2002 letting.

In order to achieve the acceleration goal presented in Commissioner Johnson's report, designers must perform a thorough analysis of the time needed for construction and use contracting strategies that emphasize timely completion.

ACCELERATED CONSTRUCTION STRATEGIES REQUIREMENTS AND APPLICATION GUIDELINES

The author has developed a set of guidelines that can be used by DOT's in implementing accelerated construction strategies. Several factors such as levels of acceleration and various flowcharts can be used as follows:

Time Determination

When determining time, the first emphasis should be continuous prosecution. Time requirements for accelerated completion should be considered for areas that have a significant impact to businesses and traffic flow. Time determination for Plan Specification and Estimates (PS&E) should be accomplished to a degree of sophistication needed for the complexity of the project. Districts may use tools ranging from simple hand diagrams to critical path method (CPM) for the analysis. A project schedule shall be included with each PS&E submission.

Strategies for Accelerated Construction:

A listing of individual strategies and levels of acceleration for construction acceleration that can be used alone or in combination is given in Table 6.

Other Tool for Minimizing Construction Time

- Use a 30, 60, 90, 120-day or other lead-time start date special provision in conjunction acceleration provisions. The lead-time will allow the contractor to fully ramp up before work begins in the ROW. The lead-time provisions may be modified to address lead-time allowances for work in the ROW but off the roadway when said work does not create travel delay.
- Work with local communities to make use of total intersection or road closure for isolated construction locations. Use milestones, calendar day definition for working day and I/D.
- Use nighttime work in urban areas and cities to reduce congestion for pavement operations. Consider construction noise, material delivery and traffic and worker safety in the decision.
- Use good sign management. Display signs only when needed. Place barricades just before work in the ROW is to begin. Place work zone speed limit signs only when speed reduction is needed. Use reasonable speed reduction (i.e., no more than 10 mph below the regulatory speed) during construction and; therefore, provide for reasonable construction speed zones in design. Remove construction barricades when the only work remaining is vegetation and plant establishment and performance periods.
- Consider removal of barricades when time is suspended in the winter for final surface placement and all other work is substantially complete, a durable full width safe pavement surface is provided, permanent markings and final safety work are complete and the only work remaining is the final

surface. Utilize a full barricade setup when the final pavement work is performed the following season.

- Maintenance projects should include standard CALD for work that is time dependent. Consider using lane rental provisions in high traffic areas when working on the pavement or lane closures are required.

Table 7. Summary Of Contract Acceleration Strategies And Levels Of Acceleration

Level	Strategies Used	Recommended Projects
0	None	Projects not meeting any of the criteria
1a	5 day Calendar Day	Majority of projects requiring an acceleration strategy. Use 5 day for most common projects. Use 6 or 7 day when higher degree of acceleration is desired and inspection staffing is available. May use project-specific definition of working day to meet lane closure restrictions in lieu of these.
1b	6 day Calendar Day	
1c	7 day Calendar Day	
2	Level 1a, 1b, or 1c, Contract Administrative LD Incentive for completion of project	Projects that significantly impact access to businesses, schools, or major traffic generations that do not reduce capacity during construction or increase capacity after construction. Do not include “No Excuse Bonus” provision.
3a	Level 1a, 1b, or 1c, Milestone for substantial project completion, Incentive and Disincentive based on Road User Cost	<u>Minimum</u> acceleration strategy for freeway construction, reconstruction or widening projects. Also for projects that add capacity or significantly improve traffic operations. These projects can show high road user costs when comparing the “before construction” conditions to the “after construction” conditions. Set milestones for distinct phases of work only. Use substantial completion milestone for last phase. Include “No Excuse Bonus” provision to ensure the contractor helps mitigate delays and to make sure TxDOT pays bonuses for <u>actual</u> early completion of milestones or project.
3b	Level 1a, 1b, or 1c, Milestones for completion of individual phases and for overall project, Incentive and Disincentive based on Road User Cost	
4	Lane Rental	Projects that frequently close one or more freeway lanes to traffic. Can be used to require working during off-peak traffic hours.
5	Level 3a or 3b plus Lane Rental	Projects that frequently close one or more freeway lanes to traffic. Even after requiring work during off-peak hours, construction generates significant road user daily costs.
6	Level 3a or 3b plus A + B Bidding	Major freeway interchanges with no known right-of-way conflicts, no unresolved environmental issues, and minimal know utility conflicts.
7	Level 3a or 3b plus Lane Rental and A + B Bidding	Major freeway interchanges with no known right-of-way conflicts, no unresolved environmental issues, and minimal known utility conflicts that frequently close one or more freeway lanes to traffic.

Procedure to Determine Road User Costs

“Road user costs” (RUC) is defined as the estimated daily cost to the traveling public resulting from the construction work being performed. That cost primarily refers to lost time caused by any number of conditions including:

- detours
- reduced roadway capacity that slows travel speed and increases travel time; and
- delay in the opening of a new or improved facility that prevents users from gaining travel time benefits.

Guidelines and procedures have previously been developed for TxDOT by TTI which detail how to determine the best suited technique for calculating road user costs.

Flow Charts for Determining RUC

The attached flow charts shown in Appendix A provide general maps of the process for determining road user costs for different types of accelerated construction strategies.

- Milestones with I/D
- Substantial Completion I/D for Added-Capacity Project
- Substantial Completion I/D for Projects Not Adding Capacity (e.g., rehabilitation, bridge replacement)
- Lane Rental

Techniques for Determining RUC

The specific techniques for calculating road user cost values are presented in the attached Table 4 (Appendix A). The type and complexity of the project influences the analytical technique used.

Values of Time used in RUC Calculations

The values of time used in RUC calculations are adjusted annually by the Texas Department of Transportation Construction Division. The most recent values as of January 2001 are provided in Table 8.

Table 8. RUC Time Values

	Passenger Cars	Trucks
Per Person	\$12.99	\$21.87
Per Vehicle	\$16.24	\$21.87
	(at 1.25 passengers per vehicle)	

Road user costs are typically calculated on a vehicular basis using passenger car volumes. However, if data is available on vehicle occupancy rates, or if the project involves high volumes of buses or other high-occupancy vehicles, the per person rates may be used accordingly. If truck volumes are high, truck values of time should be factored into the calculations for the number of trucks impacted.

Determining Accelerated Construction Strategy

If a project meets any of the criteria requiring accelerated construction strategies, the TxDOT District must determine the most appropriate method to be used. Of course, the simplest thing to do would be to just insert the calendar day definition, but that probably would not be enough to attain the Department's goals.

Identifying an appropriate strategy early in project development is highly recommended.

Identifying a suitable strategy early, the responsible party performing calculations or the need for an exception will benefit all parties involved in a project's development and ensure timely development. In some cases, the TxDOT District may want to consult with the TxDOT Division offices for direction as to how to proceed. If a strategy is chosen that will require determining road user costs, this can be handled based upon project complexity and experience of district staff. District staff may perform the calculations or seek assistance from the divisions. Until both district and division staff become more experienced with performing calculations involving computer simulation models, there are other options available to the districts. If the project is being designed by a consultant contract, provisions could be added to the agreement for the consultant to calculate road user costs as needed. Another option would be for the District to set up one or more evergreen contracts to handle these project specific calculations. TxDOT currently has an interagency agreement with the Texas Transportation Institute (TTI) and TTI has provided assistance on a limited basis in providing training and performing RUC calculations. TxDOT currently has interagency agreements with TTI in several urban districts, and through these agreements TTI offers training and technical assistance in calculating road user costs.

Time Determination Basics

Regardless of the type of schedule to be created, the following steps are needed:

Step 1. Understand the Sequence of Work and Traffic Control Plan in the PS&E

If a roadway could be completely closed to traffic, determining contract time would be an easy task. The reality, however, is that we must build projects under traffic. Traffic changes, lane closures, and detours typically determine the quantities of work available at any given time. These restrictions will also affect production rates. If a realistic time determination schedule is to be developed, it must be done following the sequence of work and traffic control plan shown in the PS&E.

Step 2. Calculate/Estimate Quantities of Work Done by Phase

Once the sequence of work and traffic control plan is understood, it is possible to either calculate or estimate the quantities of work per phase. This information is essential to assign each work activity within each phase or stage an accurate duration.

Step 3. Determine Attainable Production Rates

Once the quantities of work per phase are known. It is possible to determine attainable production rates for the various types of work. Factors that should be considered when estimating productivity rates include:

- Quantity of work
- Difficulty of work
- Time restraints
- Ease of access to the work
- Local site drainage implications

- Type of soil expected
- Material availability
- Special ornamental or decorative features
- Special considerations including
 - Pre-cast versus cast-in-place
 - Slipform versus formed concrete work
 - Daytime versus nighttime work

It is recommended that the productivity estimates be determined for one average crew performing the particular activity given the special considerations above. If it is later decided that sufficient space and work is available for two crews to conduct the same activity, the productivity rate can be doubled.

Example of Guideline Application in the Atlanta District in Small Projects

The summary of accelerated construction strategies developed has been applied to a theoretical case study to demonstrate the need and applicability of such strategies.

Two different examples have been created as follows for small projects that could be used in the Atlanta District. Examples of Substantial Completion or Milestone Incentive/Disincentive Road User Costs using RUC tables for Category III and Category IV projects (found in Appendix A) are presented as follows:

*Example 1: Substantial Completion or Milestone I/D Road User Costs
Category III Project Using RUC Tables (found in Appendix A)*

Problem: A proposed project involves the upgrade of 1.5 miles of a two-lane rural highway to a four-lane divided highway. The proposed project will have an average daily traffic (ADT) volume of 28,000 vehicles per day and 15% trucks

Table 9. RUC Calculation Factor

Two-lane Rural Highway (0-25% No Passing Zones) (in \$/day per mile)				
ADT	5% Trucks	10% Trucks	15% Trucks	20% Trucks
5000	1400	1400	150	1500
7500	2100	2200	200	2300
10000	2800	2900	3000	3100
12500	3600	3700	3800	3900
15000	4400	4500	4600	4700
17500	5200	5300	5500	5600
20000	6000	6200	6400	6500
22500	7000	7200	7400	7500
25000	8000	8300	8500	8700
27500	9300	9600	9800	10100
30000	10700	11000	11200	11500
32500	12300	12600	12900	13200
35000	14000	14400	14800	15200
37500	16100	16500	16900	17400
40000	18300	18800	19300	19800
42500	20700	21200	21800	22400
45000	23300	24000	34600	25200
47500	26000	26700	27400	28100
50000	28800	29600	30300	31100

Table 10. RUC Calculation Factors

Four-lane Rural Divided Highway (in \$/day per mile)				
ADT	5% Trucks	10% Trucks	15% Trucks	20% Trucks
5000	1400	1400	1500	1500
7500	2100	2100	2200	2300
10000	2800	2900	3000	3000
12500	3500	3600	3700	3800
15000	4200	4300	4500	4600
17500	4900	5100	5200	5300
20000	5700	5800	6000	6100
22500	6400	6600	6700	6900
25000	7100	7300	7500	7700
27500	7900	8100	8300	8500
30000	8700	8900	9100	9400
32500	9400	9700	9900	10200
35000	10200	10500	10800	11000
37500	11000	11300	11600	11900
40000	11800	12200	12500	12800
42500	12700	13000	13400	13700
45000	13500	13900	14300	14600
47500	1500	14900	15300	15600
50000	15400	15800	16300	16700

Solution:

Existing condition: Road user costs are \$8,500/day/mile
 Proposed condition: Road user costs are \$7,500/day/mile
 Difference \$1,000/day/mile x 1.5 mi.

Cost of motorist delay for each the project is delayed: \$1,500 per day

Note: RUC Tables for Category III and IV projects can be found in TTI Research Report, “Techniques for Manually Estimating Road User Costs Associated with Construction Projects.” <http://tti.tamu.edu/product/catalog/reports/407730.pdf>. (12)

Based on Table 4 Summary of Contract Acceleration Strategies, Level 3a of acceleration for this project would be the most appropriate. Level 3a of acceleration includes a combination of other strategies including: Calendar days, Milestones for substantial completion, Incentive and Disincentive. All of the above strategies would be suggested for this type of project by using the calculated Road User Cost and applying it to milestones specific to the project and for Incentive and Disincentive for early/late completion.

EXAMPLE 2: *Substantial Completion or Milestone I/D Road User Costs
Category IV Project Using RUC Tables*

Problem: One a four-lane rural highway with an ADT of 45,000 and 10% truck volume, a two-mile rehabilitation project is proposed in which four lanes will still remain to open to traffic but capacity will be restricted.

Table 11 –RUC Calculation Factors

Work Zone on a Four-lane Rural Divided Arterial – 10% Trucks (in \$/day per mile)			
One Lane Closed in One Direction		Four Lanes with Reduced Capacity	
ADT	Road User Costs	ADT	Road User Costs
5000	0	5000	0
10000	0	10000	0
15000	100	15000	0
20000	200	20000	0
25000	600	25000	100
30000	1400	30000	100
35000	2600	35000	200
40000	4300	40000	400
45000	6200	45000	700
50000	8300	50000	1300
55000	10300	55000	1800
60000	12500	60000	2500
65000	14600	65000	3400
70000	16600	70000	4500
75000	18500	75000	5600
80000	20200	80000	6800

Solution:

Road user cost from the table: \$700/day

Note: RUC Tables for Category III and IV projects can be found in TTI Research Report, “Techniques for Manually Estimating Road User Costs Associated with Construction Projects.” (12)

Based on Table 6: Summary of Contract Acceleration Strategies, Level 2 of acceleration would be selected. Level 2 of acceleration is applicable to projects that significantly impart traffic generator and do not reduce capacity during construction. This level includes a combination of various strategies including: Calendar day, Contract Administrative Liquidated Damages, Incentive for completion of project. All of the above strategies would be suggested by using the calculated Road User Cost and implementing it as liquidated damages value and Incentive for early completion.

CONCLUSIONS: PROJECT MANAGEMENT BASICS

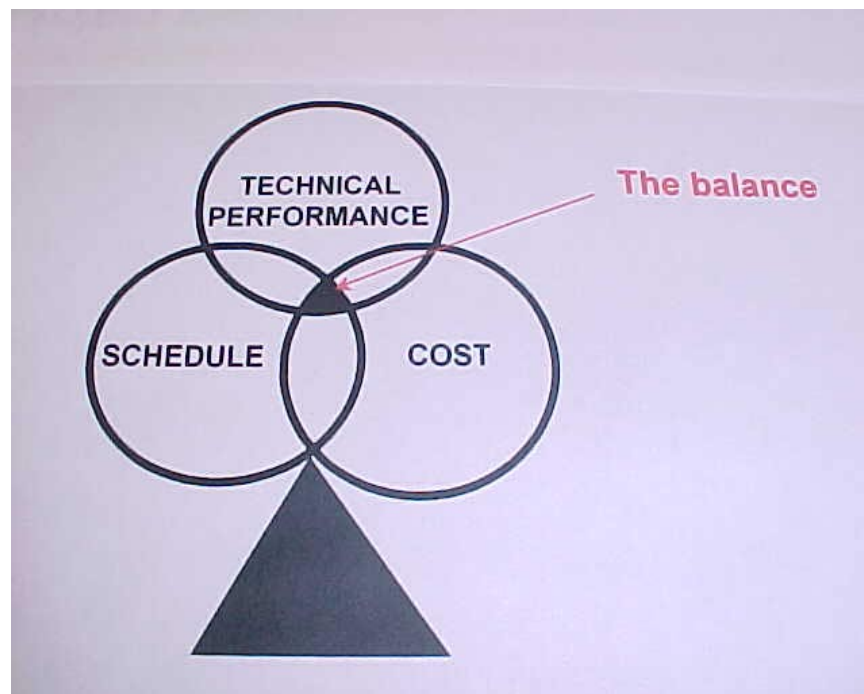


Figure 10. Balance is essential when developing accelerated construction projects.

Time requirements for each project is a critical construction component. Must be addressed non-continuous prosecution of the work. In addition, reduced construction time is a goal that can be achieved through sound engineering. Utilities and other conflicts will be encountered during construction; however, across-the-board exceptions for using acceleration provisions will not be given for these expected conflicts. Coordinate utility and other third party work early in the project life, during the planning and design stages.

The strategies provided above may be used alone or in combination for each project. Strategies for acceleration need to be discussed during the Design Concept Conference.

Critical Success Factors for Selected Methods for Construction Acceleration

Training

- All parties involved must be made aware of and understand their roles and responsibilities under the applicable contract specifications.
- SHA responsibilities will change as well as contractor specifications.
- The SHA must employ personnel with the appropriate expertise to implement a non-traditional contracting method program.

Appropriateness of Method for Projects

- Both the SHA and the contractor must possess appropriate levels of resources to execute the roles defined in the training process above.
- Criteria must be defined to make clear what projects are candidates for an alternate contract method.
- Projects chosen must match the objectives set by the SHA for implementing the alternate contracting method.

Communication

- Communication among major parties involved is crucial throughout development of an alternate contracting program as well as throughout the duration of individual projects.
- SHA personnel, contractors, sureties, and all other involved parties must clearly communicate their concerns and provide feedback to each other to improve the alternate contracting method process.
- Timely conflict resolution during the project is essential.

Initial Alignment

- All involved parties must bring their expectations into alignment and buy into the alternate contracting method early in the process.

Post-Award Alignment

- A working relationship among all involved parties must evolve and continue throughout the duration of an alternate contracting method project. Partnering is a practice that may help achieve this relationship.

Integration of Design, Construction Methods and Techniques, and Sequence of Work

- An alternate contracting method process must be identified as the chosen contract method early in the life of the project. The design, scope of work, and preparation of specifications and contract documents are examples of the elements of the project that may be affected by the choice of an alternate contracting method.
- Design consideration, selection of construction methods and techniques, and sequences of work are all interrelated and will be impacted by an alternate contracting process.

More Up-Front Investment by SHA

- The SHA must be willing to invest more resources initially in the alternate contracting method development process. As the process matures, these costs will be recouped as life cycle costs of individual projects are reduced.

Support of SHA Upper Management and Industry Buy-in

Without the approval and support of senior level management within the SHA, and the buy in of local industry personnel, an alternate contracting program can not be implemented successfully.

Table 12. Contract Time Factors

FACTORS TO BE CONSIDERED IN CONTRACT TIME	EFFECTS OF ERRONEOUS TIME
<ul style="list-style-type: none"> • Letting Dates • ROW acquisition • Utility relocations • Weather and seasonal effects • Major material acquisition and delivery • Traffic phasing • Quantities and production rates • Activity relationships 	<ul style="list-style-type: none"> • Too Little Time will result in increased prices, increased pressure and disputes over contract time. • Too Much Time will result in idle projects, public complaints, project administration costs, and increased costs to road users and businesses.

ACKNOWLEDGEMENTS

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APPENDIX A

Table 13: Categories of Candidate Projects for Application of RUC

Category	Description of Projects	Setting	Technique	Reference Guide
I	High Impact Urban Freeway Construction or Rehabilitation <ul style="list-style-type: none"> • Severe capacity reduction during construction • Phase competition time critical • Interaction with other freeway or arterial projects 	Urban	FREQ, CORSIM or HCS models	1
II	Urban Arterial Roadways <ul style="list-style-type: none"> • Signalized Intersections • Diamond Interchanges 	Urban	PASSER models	1
III	Other Added Capacity Projects <ul style="list-style-type: none"> • Highway widening projects not classified as I or II above (rural highways, suburban arterial, urban freeways) • New facility construction 	Urban or Rural	Manual Technique	1 and 2
IV	Rehabilitation and Other Non-Capacity-Added Projects <ul style="list-style-type: none"> • Paving projects (no capacity increase) • Bridge replacements • Detour routing 	Urban or Rural	Manual Technique	1 and 2

Reference 1: *A Short Course on Techniques for Determining Construction Related Road User Costs*

Reference 2: *Techniques for Manually Estimating Road User Costs Associated With Construction Projects*

APPENDIX A

Calculation of Road User Costs for Lane Rental

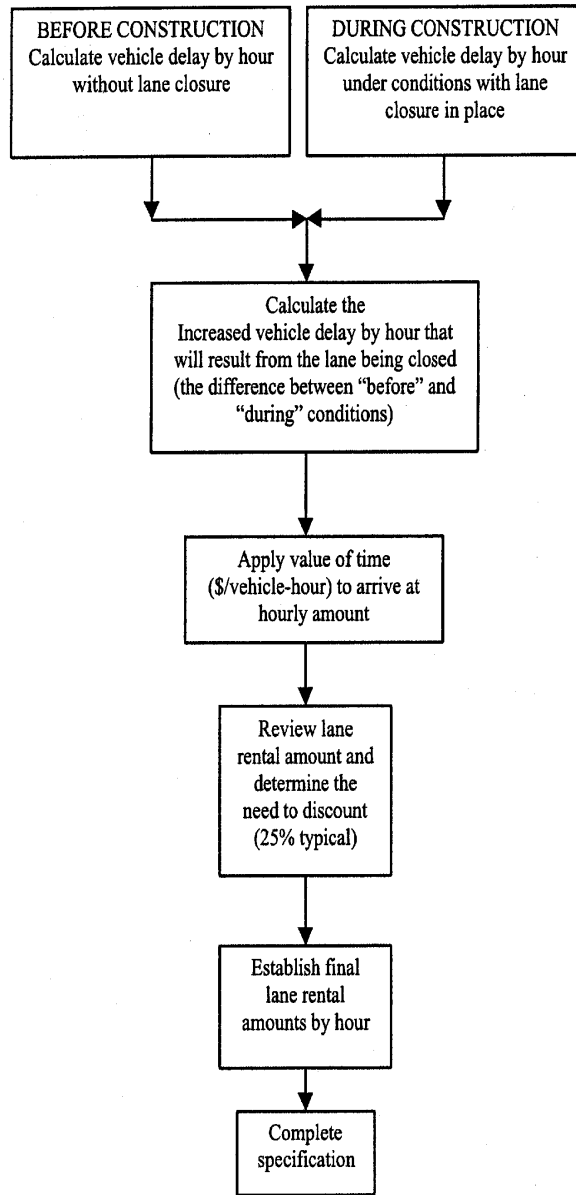


Figure 11. Calculation of Road Costs for Lane Rental

APPENDIX A

**Calculation of Road User Costs for
Substantial Completion Incentives/Disincentives (I/D)
Projects Not Adding Capacity**

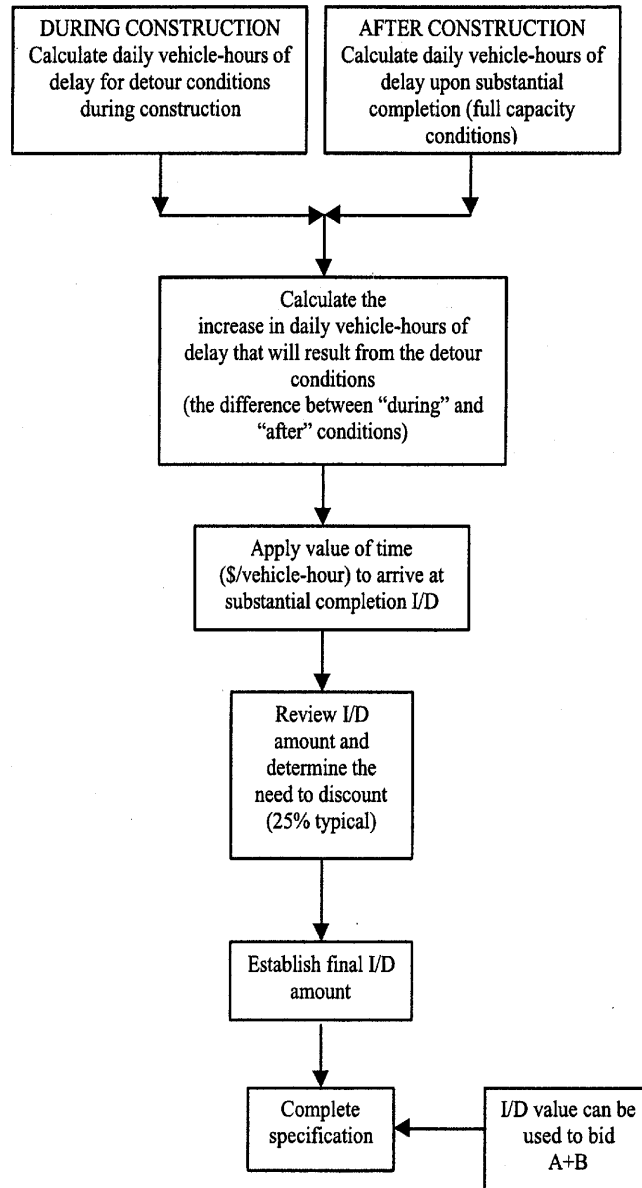


Figure 12. Calculation of Road User Costs for Substantial Completion I/D Projects Not Adding Capacity

APPENDIX A

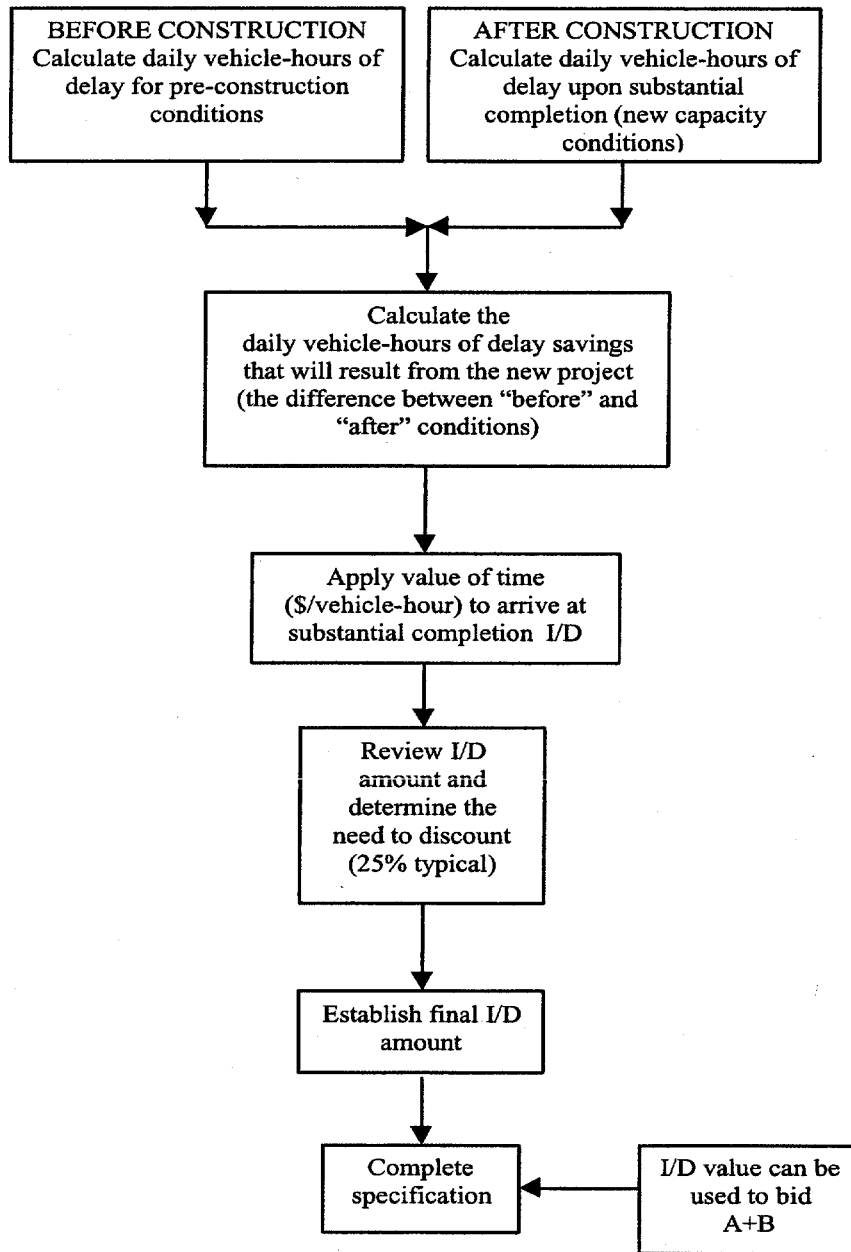


Figure 13. Calculation of Road User Costs for Substantial Completion Incentives/Disincentives (I/D) Added-Capacity Projects

APPENDIX A

Procedural Flowchart for
Preparing Lane Rental Specification

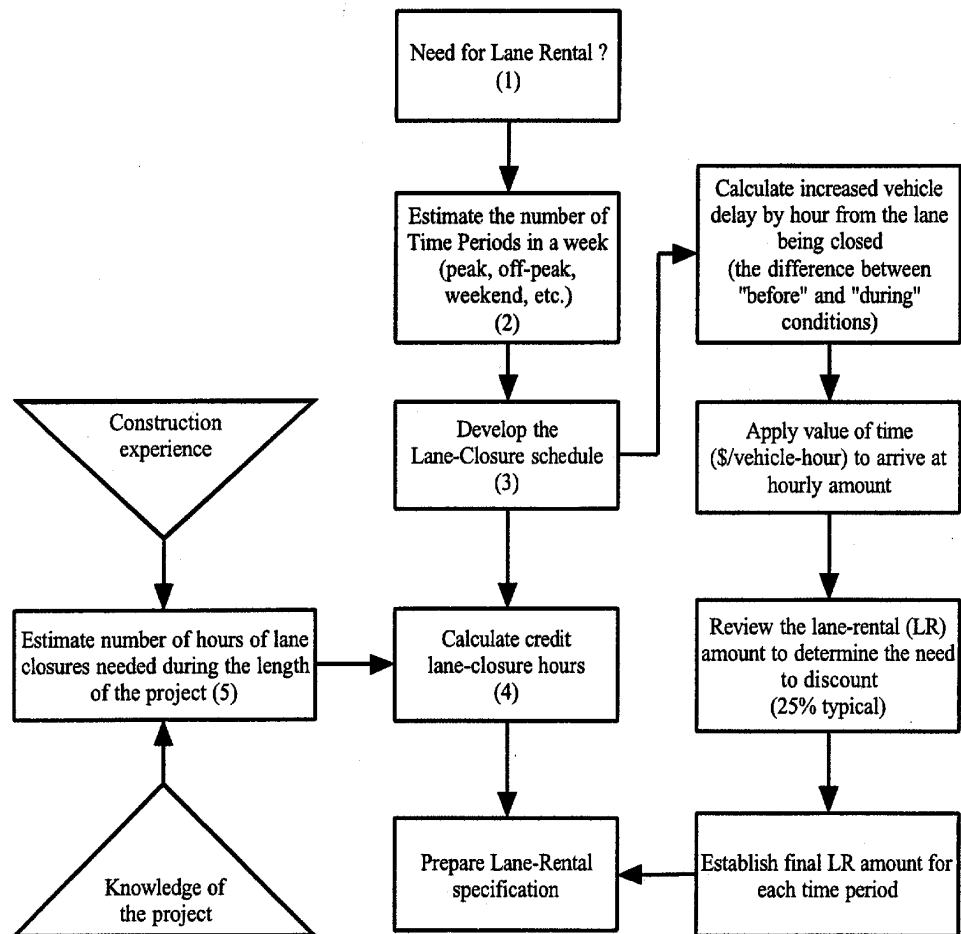


Figure 14. Lane Rental Specification

APPENDIX A

Procedural Flowchart for
Preparing A+B Specification

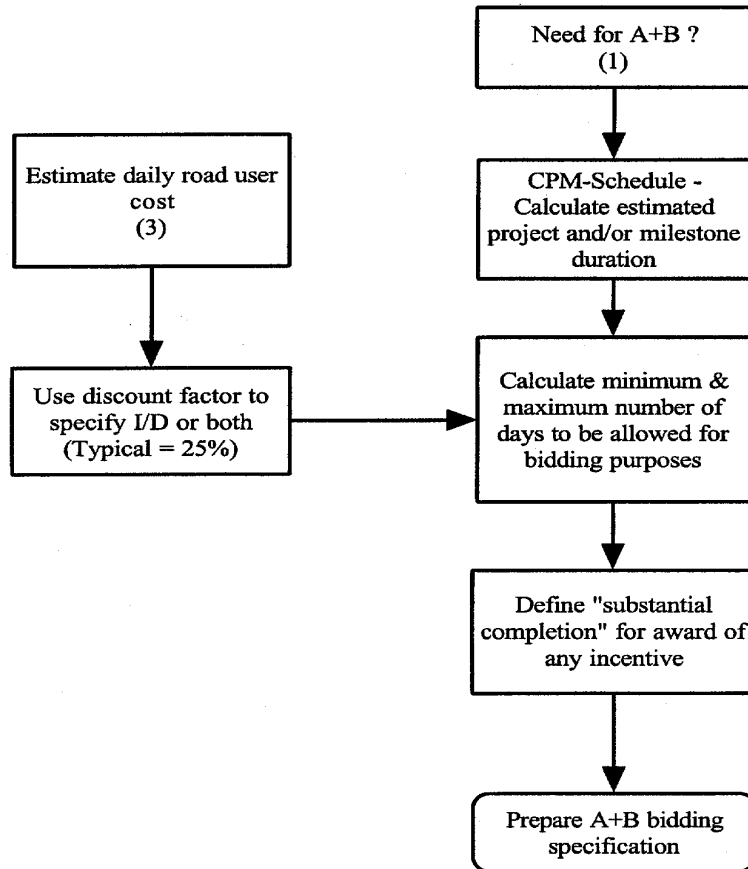
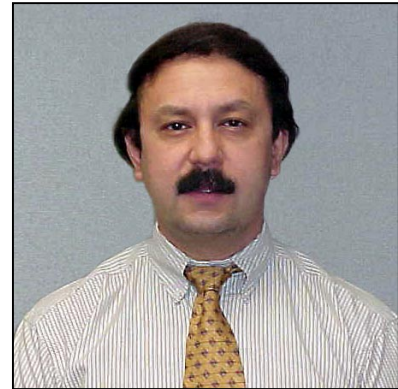


Figure 15. A + B Specification

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**LESSONS LEARNED FROM A TRAVEL TIME
INCENTIVE/DISINCENTIVE ON STATE ROUTE 68 IN ARIZONA**

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SUMMARY

Traditional traffic control methods do not encourage the contractor to manage the flow of traffic through the work zone and minimize the delay to the motoring public. A system approach is needed in order to encourage the innovation necessary to minimize travel time delay.

A means to monitor the amount of time it takes a motorist to travel through a construction work zone is needed, in combination with an incentive/disincentive clause, to ensure the management of traffic flow through the work zone by the contractor. The objective of this research is to review current practices and develop findings to assist in the implementation of a travel-time incentive/disincentive on future ADOT rural highway projects.

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INTRODUCTION

Travelers and commuters are experiencing longer travel times due to the increase in the number of construction and maintenance work zones on the highway system. Longer delays result in traveler frustration and aggressive driving behavior. Many types of innovative contracting methods (e.g. design-build and A+B bidding) have been utilized by the Arizona Department of Transportation (ADOT) to mitigate the impact of construction work zones to the traveling public. Although these are useful techniques for early completion of a project, allowing the roadway to be open to the public sooner, they often lead to travel time delays to the traveling public as a result of the intense nature of the construction activities within the work zone.

Rural two-lane highways present unique characteristics when reconstruction is needed. Most rural Arizona highways do not have a detour route available. Those routes that are available can add up to 100 miles a trip. Many times lane closures are not applicable for long periods of time due to high recreational/tourist traffic, or other such characteristics.

Real-time travel time through a traditional ADOT construction work zone is not currently measured or disseminated to the traveling public. In some urban areas around the United States, real-time travel time information is collected on freeway systems and provided to the public via different mediums such as the Internet, dynamic message signs, radio, and television.

A means to monitor the time it takes a motorist to travel through a construction work zone is needed in combination with an incentive/disincentive clause in order to ensure the management of traffic flow through the work zone by the contractor. In other words, if the contractor keeps traffic flowing through the project at a travel time similar to the travel time prior to construction, the contractor would receive an incentive. If the contractor is unable to keep traffic running smoothly, the contractor would be charged a fee.

Objectives

The goal of this research was to develop recommendations for implementation of a travel time incentive on rural ADOT construction work zones. The specific objectives were:

- Examine current practices for travel time estimation
- Examine current practices for construction incentives/disincentives
- Develop guidelines/findings for the application of a travel time incentive on future ADOT projects.

Scope

Findings were developed to assist in the implementation of a travel time incentive/disincentive for future rural ADOT projects. Urban freeway work zones were not considered as part of this research.

BACKGROUND

Two major goals are being addressed on a national, state, and local transportation level: the *safe* and *efficient* flow of traffic through construction and maintenance work zones (*L*). Since there is an inverse relationship between congestion and safety, these two goals are highly interrelated. When congestion increases, crashes increase and when crashes increase, congestion increases. According to a National Quality Initiative survey, conducted in 1995, only 29 percent of those surveyed were satisfied with the flow of traffic through work zones (*L*). This demonstrates the need for State Highway Agencies (SHA) to focus on the movement of traffic through construction and maintenance work zones with a minimum delay in travel time.

Travel Time

The Travel Time Data Collection Handbook defines travel time as the time required to traverse a route between any two points of interest (2). The measurement and dissemination of travel time information can help to improve the safe and efficient flow of traffic. It can improve the flow by providing information to the SHA about construction activities and the impact to traffic. The dissemination of travel time information can also provide motorists with information on upcoming delays and to aid in their route selection decision. In addition, safety can be improved through motorists having advanced knowledge of travel time through the work zone.

Traditionally, travel time data have been utilized in transportation planning applications. More recently, real-time travel information has been utilized in the traffic operations management arena by posting real-time camera pictures or traffic flow patterns on the Internet. Most recently, real-time travel information is being utilized in freeway work zones to improve the safety of workers and motorist while providing real-time traffic information to drivers which assists in maintaining traffic flow through the work zone (3).

In addition, there are a number of techniques available to measure and collect travel time information. Table 1 contains information extracted from an ENTERPRISE report *Maintaining and Estimating Travel Time Within Construction Zones* that demonstrates which techniques are most applicable to measuring work zone travel time (4).

Table 1. Work Zone Travel Time Measurement Techniques (4)

Technique	Description
Video Detection System	Video cameras with optical character recognition software that detects license plates at set locations in the project.
Induction Loops	Inductive loop detection that classifies vehicle characteristics at locations through out the project.
Point Speeds	Detectors used to measure vehicle speeds that are applied to the distance to compute travel time.

Innovative Contracting Methods

Traditional contracting methods base the selection of a contractor on the low-bid of a responsive bidder. Innovative contracting methods place the emphasis on performance criteria. Table 2 contains a listing of some innovative contracting techniques. A number of the techniques being utilized by the Arizona Department of Transportation are shown in the table; however, there are numerous other techniques that are not represented.

The number one reason to utilize these techniques is to shorten the duration of the construction project. Although there are a number of advantages to utilizing these techniques, many times there are disadvantages that are forgotten or overlooked. Compressed work schedules can cause worker fatigue and burnout. This in turn can cause an increase in job site accidents or near misses. In addition, many resources (agency and contractor) are taken from other projects in order to concentrate on projects with shortened durations. At times, shortened overall project durations are needed. This usually causes multiple flagging stations or closures within the project limits due to the contractor working in multiple areas at one time. However, there are times when the flow of traffic through a work zone needs to be

maintained at conditions similar to those conditions prior to construction. Those times usually occur when there is no reasonable detour available for the project. All of these disadvantages along with the advantages have to be weighed heavily when utilizing these contracting methods.

Table 2. Innovative Contracting Techniques Used By ADOT

Technique	Description (5)
Design-Build	Single entity provides both the design and construction
A+B Bidding	Selects the low bidder based on a monetary combination of the contract bid items (A) and the time (B) needed to complete the project
Lane Rental	Charging of rental fees for occupying lanes, shoulder, or combinations to perform the work
Incentive/Disincentives	Provides a way to compensate the contractor for completing work ahead of schedule or assesses the contractor for completing work after the scheduled completion date

TRAVEL TIME INCENTIVE

According to Mark Edwards with the American Automobile Association, ninety percent of personal travel is by automobile and eighty-four percent of general freight is moved across the highway system. In addition, delays in construction are costing \$43 billion with \$21 billion in extra fuel (6). This demonstrates the need for a Work Zone Traffic Management System that is more inclusive than traffic control. These statistics emphasize the need for strategies to keep people moving efficiently through a traffic corridor, which is in line with the goal described earlier of safe and efficient flow of traffic through construction and maintenance work zones. The key to this problem is to minimize motorist travel time delays during construction and maintenance operations. More consideration needs to be given to the needs of the customers to keep travel times through the work zones similar to those before construction activities begin. One methodology to resolve this problem is to combine a standard incentive/disincentive feature with a real-time travel time system.

Case Study – SR 68 Design-Build Project

State Route 68 is located in northwest Arizona and runs between Kingman, AZ and Bullhead City, AZ, which is directly across the Colorado River from Laughlin, NV (Figure 1).

The SR 68 project was a \$42 million project covering 13.5 miles. The scope of the project was to reconstruct the existing 2-lane highway into a 4-lane divided facility. The project encompassed a rural corridor that spans the Black Mountains that are a Bureau of Land Management designated Area of Critical Environmental Concern. There were six structures at three locations. Two of the structure locations were to facilitate Big Horn Sheep crossing underneath the highway and the third structure location was for drainage purposes. The project included numerous box culverts and pipe crossings as well as catch basins for drainage. The project consisted of one and one-half million cubic yards of excavation with one million cubic yard of rock excavated by blasting. There were approximately 200,000 tons of asphaltic concrete paving and 10,000 tons of asphalt rubber- asphaltic concrete friction course.

Due to the sensitive desert environment, over 8,000 cacti and plants were located to a nursery during construction and replanted on the project once construction was complete.



Figure 1. Project Location Map

Although the corridor is regarded as rural, it is considered a commuter route for people traveling between Kingman, Bullhead City, and Laughlin. Also, ten percent of traffic is trucks and a significant number of recreational users travel the corridor. State Route 68 also serves as an alternative route to Las Vegas from Kingman, AZ. Motorists can travel to Las Vegas via US 93 over the Hoover Dam or via AZ SR 68, to NV SR 163, to US 95 into Las Vegas.

Due to these unique characteristics, the Kingman District of ADOT wanted to minimize the construction delay to all the motorists on a day-to-day basis. A Traffic Management Incentive specification (Appendix A) was included in the project. The purpose of the incentive was two fold:

1. Traffic Management System to provide motorists with information regarding travel time to Las Vegas via SR 68 or US 93 over the Hoover Dam; and
2. Traffic Management Fund (Travel Time System) as an incentive to facilitate the flow of traffic through the project.

Some difficulties arose in reference to the first part of the incentive program. There were no electrical or telephone lines near the Hoover Dam unless the system was placed on the Nevada side of the Hoover Dam in Boulder City. The closest electrical and phone lines on the Arizona side were 16 miles from the Hoover Dam. In addition, there were concerns with the accuracy of the information to be displayed to the public since the travel time from the Hoover Dam to the Las Vegas City Limits would be historically estimated and not physically measured. Due to these considerations, ADOT elected to remove the Traffic Management System part of the Traffic Management Incentive.

Prior to construction, the average time to travel the project limits, which was posted at 55 MPH, was 17 minutes. During construction, traffic control measures, and reduced posted speed limits of 35-45 MPH increased the corridor travel time to approximately 21 minutes. The incentive for the project included a provision that during construction the travel time could not exceed an average of 27 minutes. The travel time was averaged every ten minutes and the incentive was based on thirty-minute intervals. The contract provided a \$400,000 travel time budget item to be drawn against on a \$21.50/lane/minute basis if the

target travel time was exceeded (i.e. if a thirty minute interval showed an average travel time exceeding 27 minutes). The funds remaining in this item at the end of the contract would be paid to the Design-Builder. However, if the travel times exceeded the target travel time and the entire funds were used, the item would turn to a disincentive where the Design-Builder would be responsible for paying for the added delay.

The contract did not specify what type of technology to implement for the Traffic Management System. The Design-Builder chose to deploy a license plate reader system developed by Computer Recognition Systems. The system included a camera and a light source to capture license plate images of passing vehicles entering the project (Figure 2). The system was mounted behind construction signs to keep from distracting the motorists.



Figure 2. Camera Site

The license plate number was taken from the picture by image recognition software, encrypted, and sent to the central computer at the contractor's office. There was a second camera at the end of the project, which also took the license plate image, encrypted it and sent it to the central computer. The central computer matched the license plates that entered and exited the project. The cameras are located in both directions of travel for a total of four cameras on the project (Figure 3). The camera and light system was operated 24 hours a day. The license plate reader system was able to match 11 percent of license plates. This rate is considered adequate compared to other license plate detection systems and for the application of the system.

During the bidding process, the Design-Build team considered other technologies for the travel time incentive. These included cellular phone tracking, vehicle probes, and radar systems. The Design-Builder chose the license plate detection system due to the capability for direct measurement of corridor travel times.

For the most part, the Design-Builder was able to maintain traffic flow through the project during construction similar to the time it took to travel the project before construction began. The contractor was charged \$14,857 against the \$400,000. Therefore, the contractor received 96 percent of the incentive amount at the end of the project.

contingencies if they are needed. Although there were some difficulties, the major benefit to the system was the demonstration to the traveling public that we were listening to their needs and minimizing the travel time through the project (Z).

FINDINGS

Through the course of discussing the SR 68 Design-Build project with the District Engineer, Project Supervisor, the Design-Builder and other construction staff both within ADOT and outside of ADOT, various practices were identified for the successful implementation of a travel time incentive/disincentive system as well as characteristics for future implementation of such a system.

Management Support and Public Outreach

As with most work done by any agency or company, implementation of an idea must have the support (financial and cultural) by management in order for the realization of success. Management support empowers people to act and to become innovative in their thinking.

Public Outreach is critical in the success of any incentive program and most importantly on a system that is high tech but still in its infancy. When the travel time incentive is utilized, it is important to communicate its use to the public in order to demonstrate that the sponsoring agency is looking at new ways to meet the needs of their customers. It is important to include the public during the development and the selection of the Traffic Management Systems and to communicate to the public once the systems are selected.

Demonstrated Need

Similar to those guidelines developed in ADOT's A+B Bidding Guide and other guides available from other agencies, one or more of the following should be met to include the travel time incentive in the project:

- Important Corridor Location
- Number of projects under construction in the area. The more projects that are in the area/district, the more need there is to minimize the delay to the motoring public.
- Closures or detours that have a high impact on businesses
- Detours that are lengthy and unreasonable
- Road User Costs exceed \$3,000 per day. Calculation should be based on ADOT's A+B Bidding Guide (<http://www.dot.state.az.us/roads/constgrp/innovations.htm>)
- Highly sensitive project (political concerns, significant public benefit, gap completion)

Pilot Project

The SR 68 Design-Build project was a unique project. The fact that it was a design-build project made the project distinctive since it was the first rural design-build project that ADOT had undertaken. There were several innovative features associated with the project that could have had an impact on the success of the travel time system. These features included lane rental, a motorist assist patrol, and a quality workmanship incentive. It is recommended that a pilot project be chosen that does not have any other innovative features that could bias the success rate of the system. This would allow for a controlled study to determine if the other innovative items on the SR 68 project contributed to the success of the travel time system.

A project should be selected in which the real-time motorist information system can be implemented. To-date, ADOT has not utilized a real-time motorist information system on a construction project. This

would allow the integration of the travel time incentive with the real-time motorist information system as was originally intended on the SR 68 project.

CONCLUSION

Although there are many innovative contracting methods available today, those methods concentrate on completing the project earlier and many times at the expense of the traveling public. Opportunities exist for other types of innovating contracting methods to encourage the management of traffic flow through the work zone. A travel time incentive/disincentive feature in a project can successfully merge the two transportation goals of the safe and efficient flow of traffic through work zones.

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APPENDIX A

Traffic Management Incentive:

Traffic Management System:

The Design-Builder is required to develop a system that will efficiently measure travel within the project limits and communicate, to the general public, the impact construction will have on off-site traffic. Development of this system is necessitated by the extreme length required for any detour around this project. SR 68 carries substantial commuter traffic between the Kingman, AZ area and the BHC/Laughlin area. In addition, the SR 68 corridor is utilized as an alternate route if the Hoover Dam crossing on US 93 is congested or closed due to incidents. It is important that the Design-Builder's system efficiently manage traffic through the project and limit delays.

The system shall include intelligent traffic devices placed on westbound Interstate 40, prior to the Beale Street exit, and on US 93 north of Kingman, prior to the exit of SR 68. These devices will show the actual time it would take a traveler to drive from Kingman, Arizona to Las Vegas, Nevada, under the current road conditions. Time will be shown for each of the two main routes between these cities.

The duration of travel from Hoover Dam to Las Vegas and from the Laughlin Bridge to Las Vegas shall be determined by agreement between the Engineer and the Design-Builder. Input from the Nevada DOT may be used in reaching this agreement. Travel time through the project, as well as the current time to travel from Kingman to Hoover Dam will be determined by the Design-Builder's approved measurement system. The Design-Builder shall provide technology that will formulate the timing for each route. The sum of the travel times will be displayed on the intelligent traffic devices placed at the locations described above.

The travel time will be shown for each of the routes listed below:

- a) Via US 93 to Hoover Dam to Boulder City, Nevada to Las Vegas, Nevada (final point is the Las Vegas City Limits)
- b) Via US 93 to SR 68 (through project limits) to BHC/Laughlin, Nevada to SR 163 in Nevada to US 95 in Nevada to Las Vegas, Nevada (final point is the Las Vegas City Limits)

These devices will show the actual travel time via electronic format displays at the general areas specified above. The electronic signs shall show the time it takes to travel the above routes under current roadway conditions. Updates shall be provided every 10 minutes. These devices will alert travelers in advance of the decision points for travel to Las Vegas, Nevada. The Design-Builder shall submit the technical proposal for this pre-travel, actual time display to the Engineer prior to ordering. The proposal will include the technology proposed, placement, utility connections, technology used to formulate the timing, reporting system and other details as are pertinent to its operation.

As a part of the proposal presenting the traffic management system, the Design-Builder shall submit a report on the relevant technology it is proposing. The Design-Builder will demonstrate that the proposed system will adequately measure and report the time of passage of vehicles traveling through the construction zone and the travel time between Kingman and the Hoover Dam. Reports will be generated by a computer program approved by the Engineer. The Design-Builder's submittal shall include all technology, reporting system, layout and other items necessary to provide an adequately functioning system complete in place. In its schedule, the Design-Builder shall allow sufficient time to permit demonstration of the components, if requested.

The traffic management system shall be approved and installed before work may start. The part of the system that measures travel time through the project shall be operative during all working hours. The message systems showing the actual time of travel from Kingman, through the project to Las Vegas (and reverse) shall remain in place and working at all times. The system will be placed only on the State of Arizona highway system, although the Design-Builder may utilize existing sign structures, if approved by the Engineer.

Traffic Management Fund:

A fund of \$400,000 has been established as an incentive for the Design-Builder to facilitate the flow of traffic through the project. If the average time of passage is more than the allowable, the fund will be reduced in accordance with the procedure given below. On its final progress payment, the Design-Builder will be given any balance remaining in the incentive fund.

If traffic management costs exceed the established incentive fund, the excess will be deducted from monthly payments due the Design-Builder. The traffic management incentive provisions do not affect the provisions of Subsection 108.09 of the specification which remains in effect.

Calculation of Incentive:

The Design-Builder shall submit computer-generated, formatted data to the Engineer that will illustrate the actual travel time through the project limits. Travel time will be based on the reported average for each thirty minute period. The Design-Builder will provide daily reports showing the average travel time for each thirty minute period. A deduction will be made from the incentive fund if the travel time exceeds the allowable given below. For purposes of this incentive the project limits will be defined as MP 1.23 to MP 14.5.

The average time of travel through the project, at the present, has been determined to be 17 minutes for both eastbound or westbound travel. This time is based on being able to use the existing climbing/passing lanes. Since the project will be under construction and the safety of the Design-Builder and the traveling public is a concern, an additional 10 minutes of travel time will be allowed. For each minute over that time (17 minutes + 10 minutes = 27 minutes) - \$21.50 per minute, per direction, will be deducted from the incentive.

For example: If travel time in each lane is measured at 30 minutes, the deduction from the incentive fund would be calculated as follows:

Eastbound: 3 minutes x \$21.50/minute = \$64.50

Westbound: 3 minutes x \$21.50/minute = \$64.50

Total deduction from incentive = \$129.00

If work is in an area for which there is an approved lane closure, in accordance with the lane rental incentive, this incentive will not apply.

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TESTING DMS FOR NTCIP COMPLIANCE

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SUMMARY

The National Transportation Communications for ITS Protocol (NTCIP) was developed to address a rising problem of non-compatibility between the devices used in Intelligent Transportation Systems (ITS). This report was written to address one specific device, the dynamic message signs (DMS) – or more commonly called the variable message sign – and how to assure a DMS meets NTCIP standards. It is intended for an agency that has acquired, or wants to acquire, a NTCIP compliant DMS yet has little or no technical knowledge available to assure the DMS is truly NTCIP compliant. The report contains an introduction to the NTCIP/ITS/DMS lingo, a more detailed background of NTCIP, a discussion of what testing a DMS means and the NTCIP standards you should test for, a method on how to test a DMS, what the future holds for testing, help in compiling contract specifications for acquiring a NTCIP compliant DMS, and the results of a case study.

Before the research began for this paper, the author was not an expert in NTCIP. With the help of many professionals in the field of NTCIP testing, the author progressed through the process of testing a DMS for NTCIP compliance. The lessons that he learned are summarized in this paper. It is the hope of the author that those reading the paper will learn from his experience and be able to easily overcome some of the obstacles that were encountered.

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BACKGROUND

History of Dynamic Message Signs

Signs that can display more than one message have been around for decades in one form or another. They began with simply placing an overlay on a static sign. Then came rotating messages and changeable message signs with neon tubes similar to a sign in the window of a tavern. They evolved from there into more complex devices to their present day status with the ability to do full motion video. Their name has changed along with this; they were first called changeable message signs (CMSs), then variable message signs (VMSs), and more recently they have been called dynamic message signs (DMSs).

History of Intelligent Transportation Systems

Along with the evolution of DMS came the evolution of a field that was first called Intelligent Vehicle Highway Systems (IVHS) and which is now called Intelligent Transportation Systems (ITS). In 1991 U.S. Congress mandated the creation of "ITS America" to coordinate the development and deployment of intelligent transportation systems in the United States (1). ITS devices include everything from actuated traffic signal controllers ... to environmental weather stations ... to highway advisory radio ... to dynamic message signs. All of these devices have seen significant changes in the last 20 years. As the systems developed and proved their worth, they have been appearing with increasing numbers in the transportation systems that we drive today.

History of the National Transportation Communications for ITS Protocol (NTCIP)

As the number of ITS devices grew, they began to be integrated into a central control system to be operated or monitored from a remote location. As the pieces began to come together, it became apparent that the same device from different manufacturers were not interchangeable or interoperable and they could not share communication lines. In order to get them to work together, it was necessary to hire a software programmer who would have to learn each devices proprietary communications structure and write a program to translate. The result was expensive software development that was not always successful.

In 1996, the National Electrical Manufacturers Association (NEMA) teamed with the Institute of Transportation Engineers (ITE) and the American Association of State Highway and Transportation Officials (AASHTO) under a Federal Highway Administration (FHWA) cooperative agreement to create the Joint Committee on the National Transportation Communications for ITS Protocol (2). This committee (along with many subcommittees) created a series of standards to which ITS equipment can be built. As a result, any ITS device that is built to this standard should be interoperable and interchangeable for basic functionality and should be able to share expensive communications infrastructure.

The ultimate goal of NTCIP standards is to make ITS devices as interchangeable as the telephone in your home. It doesn't matter if your telephone is a Bell South, Uniden, or Panasonic; once plugged into the wall, it can communicate with millions of other phones across the world. The same will eventually be achieved with ITS devices. It should not matter if your sign is a Daktronics, Skyline, Vulcan, or 3M. Once it is plugged into the system, it should operate seamlessly with central software.

If NTCIP standards are followed, the ITS industry will have plug-n-play equipment with off-the-shelf software that can communicate over one set of wires.

NTCIP STANDARDS FOR DMSs

According to the ITS Standards homepage, there are 91 NTCIP standards (3) that have been developed or are currently being developed. Each standard is an individual document that pertains to a specific portion of the NTCIP. These are technical documents that will seldom be used after the equipment is operational. Fourteen of these standards apply to DMSs (4). They are below. At the end of the name of each standard is the status. "In Ballot" means that it is presently being voted on.

1. Application Profile for File Transfer Protocol (FTP) – NTCIP 2303 – Published
2. Base Standard: Octet Encoding Rules (OER) – NTCIP 1102 – In Ballot
3. Subnet Profile for Ethernet – NTCIP 2104 – In Ballot
4. Subnet Profile for Point-to-Point Protocol using RS 232 – NTCIP 2103 – In Ballot
5. Transportation Transport Profile – NTCIP 2201 – In Ballot
6. Simple Transportation Management Protocol (STMP) – NTCIP 1103 – Under Development
7. Subnet Profile for PMPP Over FSK modems – NTCIP 2102 – In Ballot
8. Simple Transportation Management Framework (STMF) – NTCIP 1101 – Published
9. Class B Profile – NTCIP 2001 – Published
10. Global Object Definitions – NTCIP 1201 – Published
11. Object Definitions for Dynamic Message Signs – NTCIP 1203 – Published
12. Point to Multi-Point Protocol Using RS-232 Subnetwork Profile – NTCIP 2101 – Published
13. Application Profile for Simple Transportation Management Framework (STMF) – NTCIP 2301 – Published
14. Internet (TCP/IP and UDP/IP) Transport Profile – NTCIP 2202 – Published

Which Standards do You Test?

All 14 of these standards are highly technical documents that are really only applicable to the maker of the DMS and the programmer of the central software. Each standard can best be described as one of three types: data dictionary standard, message set standard, or protocol standard (5). Testing the standards that apply to the message set or protocol can be very technical and easily beyond the technical ability of a transportation agency. However, there is a simple logic jump that can assist a transportation agency in testing a DMS for NTCIP compliance.

Data dictionary standards are page after page of object definitions. Object definitions are variables that are used by the programmers to do specific things or to hold specific information. For example, the object definition "*dmsSignType*" can be assigned an integer as shown in Figure 1 (6).

When the object definition "*dmsSignType*" is sent to the controller, it should return one of the values listed in Figure 1 that correctly reflects the type of DMS. For example, if the value associated with *dmsSignType* is 131, the device is a portable changeable message sign.

Two of the standards listed above are data dictionaries that are applicable to DMS: NTCIP 1201 (Global Object Definitions) and 1203 (DMS Object Definitions). A simplified view of testing a DMS can be to test for the object definitions contained in the data dictionaries using a standard desktop computer. If the test is completed successfully, then the entire message set and protocol standards should have been met in order for the communication to happen.

2.2.1.1.1.2 Sign Type Parameter	
<i>dmsSignType</i>	OBJECT-TYPE
SYNTAX	INTEGER{
	other (1),
	bos (2),
	cms (3),
	vmsChar (4),
	vmsLine (5),
	vmsFull (6),
	portableOther (129),
	portableBOS (130),
	portableCMS (131),
	portableVMSChar (132),
	portableVMSLine (133),
	portableVMSFull (134)
	}
ACCESS	read-only
STATUS	mandatory
DESCRIPTION	"Indicates the type of sign."
	--The descriptions are:
	--other: Device not specified through any other definition, refer to device manual,
	--bos: Device is a Blank-Out Sign,
	--cms : Device is a Changeable Message Sign,
	--vmsChar : Device is a Variable Message Sign with character matrix setup,
	--vmsLine : Device is a Variable Message Sign with line matrix setup,

Figure 1. Sample Object Definition from NTCIP 1203

This type of test will prove that interchangeability can be accomplished. However, there is indication that this type of simplified test may not assure interoperability (7). Indeed for the Case Study a direct serial connection was made with the DMS controller with no other device in the system. As a result interoperability and protocol standards were not tested. In theory this should not be a problem as each DMS controller is assigned a unique identification called a "drop address". If the drop address is truly unique, there should be no problem with operating the DMS as part of a system. In addition, to test for true interoperability would require an expensive testing lab with not only DMS controllers, but with several other types of ITS devices thus prohibiting the standard agency from testing interoperability (8).

Why Test?

For years agencies have built capital improvements and have come to understand that you don't always get what you intended. This can be caused by something as simple as misunderstandings in the plans or contract specifications. Testing the product that you purchase is simply a way to be assured you get what you asked for.

SETTING UP THE TEST

Test Procedure

Before you begin a test, you need to have a test procedure. The ENTERPRISE Consortium (a pool-funded study with members from North America and Europe) funded the creation of a test procedure (9). The procedure was developed by Trevilon Corporation and is available at the following web site

<http://www.trevilon.com/dms.pdf>. It is believed that this is the only test procedure that is publicly available for DMS. Other agencies have modified this procedure for their own benefit (10).

Test Software

Testing of a DMS is done with a software program called the Exerciser. The program is public domain and is available at <http://www.ntcip.org/library/software/abstract.asp?AbstractID=66>. As of the writing of this report, it is the primary software application that is available for testing NTCIP compliance and the test procedure mentioned above was written for this software. It was last updated in November of 2000 (11) and has no technical support. To conduct the test procedures is a cumbersome and time-consuming task. The power of the program lies in its ability to run macros (small programs that combine several steps into a single program). If an agency were to really get into testing a number of DMSs, it would pay to invest significant time into creating macros so that just executing one macro could run a series of test procedures.

In July 2002 a new program was released to test NTCIP compliance of DMSs. Trevilon developed this program for the ENTERPRISE consortium. The program is called NTester 1.1 and is available for free from Trevilon. Because the program was only recently made available, only a short test of the program was conducted. Even though the test was short, it was apparent that the NTester will go a long way in improving DMS testing. The program is user-friendly and testing can be accomplished using a simple checklist type procedure. (12)(13) There still is a problem that the program will not support direct serial linkage between a computer and a controller although this is currently under development. The fact there is no serial connection can be overcome by simply conducting the test using two modems and a “dial-up networking” connection in Windows.

Southwest Research Institute has developed a testing program for the Texas Department of Transportation (TxDOT) that is designed to automate the NTCIP testing process so that it can be operated by a technician. The program is called TNT (TxDOT NTCIP Tester) and has been used to test several DMSs (14). The basis for the program is the TxDOT testing procedure. Once familiar with the program a complete test takes about 20 minutes to run (15).

A third program, from Frontline Testing Equipment (FTE), is available for monitoring the information that travels down the communication wires. The program is intended for detailed analysis of NTCIP communication protocols and does not allow the user to input object definitions (16). Since it does not allow a user to selectively test object definitions, this software was not used in the case study.

WHO SHOULD TEST?

NTCIP standards are technical documents and are not easily comprehensible by a Civil Engineer employed by a transportation agency. There is a significant time investment required before a person can become familiar enough with NTCIP to comprehend the test and outcome. Because of the significant time investment, an agency cannot afford to have a whole team of testers. Therefore your testing knowledge lies in one individual and should something happen to that individual, you have to start all over again.

There are consultants available to test for NTCIP compliance. Three consultants are Trevilon, Battelle, and Southwest Research Institute. All of these entities are available should an agency decide to not invest the time or money in training their own individual. The benefit of a consultant is that you get an expert in the field of NTCIP that will be up on the speed with the latest standards. They will also come with their own tools necessary to conduct the testing.

FUTURE OF TESTING

Testing ITS devices for NTCIP compliance is truly a new area of expertise. As such, there are few people who presently understand how to conduct testing and of those few, they do not all agree on how to test (17). The Joint Committee on the NTCIP has formed a new working group specifically for testing and conformity assessment. The first work item will be the development of a template for NTCIP roadside device test procedures (18). The work group will have to overcome some disagreements among NTCIP experts on how testing should be conducted and what is a pass or fail test. Since the work group is presently being formed, it will probably be some time before there is a product regarding DMS Testing. The progress of this work group can be tracked at the NTCIP web site (<http://www.ntcip.org>).

The ENTERPRISE Consortium is funding the INCH (Integrating NTCIP Compliant Hardware) program to specify, procure, install and test NTCIP-compliant hardware (19). Their work has already benefited the NTCIP community and it appears as if the pool-funded study will continue. Check their web site at <http://enterprise.prog.org> for progress before embarking on NTCIP testing of DMSs.

CONTRACT SPECIFICATIONS

Acquiring a NTCIP compliant DMS is not necessarily as simple as asking for a NTCIP compliant sign in the contract specifications. There may be additional features that you would like or additional features that the vendor would like to provide to make the system operate better. The NTCIP standards were not intended as a complete answer to everything, but as a solid base of standard functions. Currently, DMS manufacturers do not limit their functionality based upon NTCIP, but use it as a base and build on it to provide additional functions at the request of the client (20)(21). Once enough people want or use the new functions they will be added to the standard. As a result the standards will not hinder innovation, the marketplace, or technology (22).

CASE STUDY

Equipment Used

For the case study, a Toshiba Pentium III, 600 MHz, laptop running Windows 98 was used. Connection to a Daktronics controller was established via an RS 232 cable with a Null Modem converter. The cable was plugged into Port J32 on the front of the controller and into the serial port on the back of the laptop. A computer monitor and keyboard were attached to the Daktronics controller to monitor the controller.

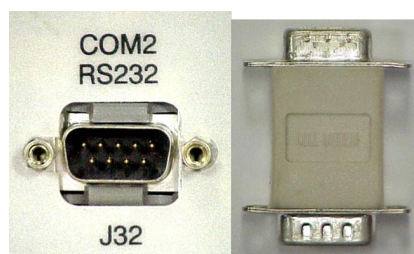


Figure 2. Port J32 and a Null Modem

Physical Hookup Issues

Before operating the NTCIP testing software, the software that was developed by Daktronics for their signs was installed on the laptop and a connection was made to the controller. This step assured that the controller was indeed working correctly and was able to communicate with the software that was designed to control it. Communication was successful with a baud rate of 9600 and was communicating through COM1 on the laptop and COM 2 on the controller.

Setting up the Exerciser

The Exerciser was chosen as the software to conduct the test because it was the only available software that was discovered near the onset of the research and it is used by the Washington State Department of Transportation (WSDOT) in the Seattle office. It is available for download from the web at <http://www.ntcip.org/library/software.asp>. The software was initially installed on a computer running Windows 2000. The program would never successfully communicate with the controller in the Windows 2000 environment. After discussion with Mark Morse of the WSDOT, it was mentioned that the program seemed the most stable on a Windows 98 computer. The program was transfer to a laptop running Windows 98 and ran successfully on this platform with no more problems.

To setup the program required that two initialization files (called INI files) be changed. The first INI file is called "NExerciser.ini". It was opened in Notepad and the COM port number and baud rate were changed to match the controller. The baud rate is the number (i.e. 9600) just below the COM#.

The second INI file is called "set-msg.ini". It, too, was opened in Notepad and the community name was changed from "public" to "administrator." The community name should be checked with the manufacturer of the DMS. For Daktronics, the community name for read-only access is "public" with no capital letters. For full read-write access, the community name is "administrator" with no capital letters. The address drop was also checked to agree with the "sign address" that is on the dial switch on the front of the controller.

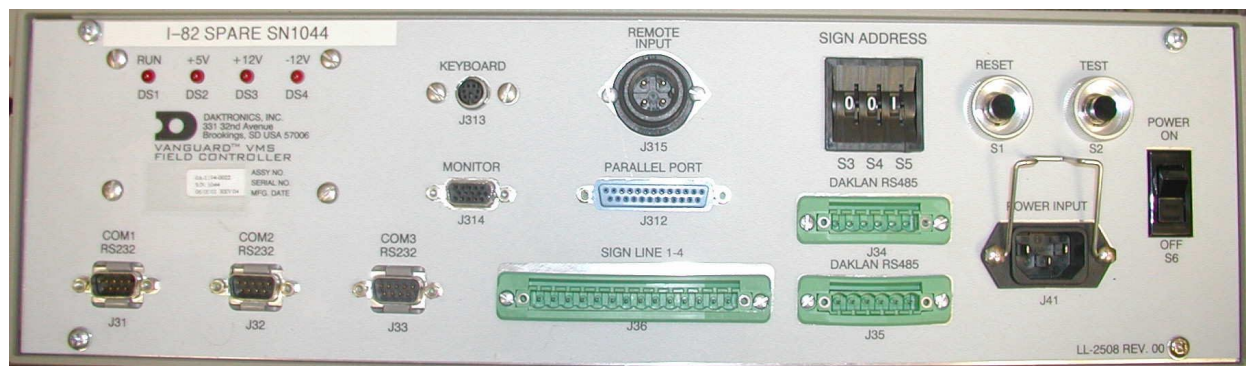


Figure 3. Face of Daktronics Controller

Test Procedure

The WSDOT is a member of the ENTERPRISE Consortium and uses the ENTERPRISE testing procedure that was discussed earlier in this document. The procedure was modified by the WSDOT to cut its length down from 31 pages, to 16 by cutting out sessions that tested features that may never be used by WSDOT. For the sake of time, the WSDOT procedure was used rather than the ENTERPRISE procedure.

Sessions

Both the ENTERPRISE and WSDOT test procedures have what are called “sessions.” The sessions are a group of object definitions that are sent to the controller. An example of DMS testing session from the ENTERPRISE procedure is shown in Figure 4.

<i>Session Name</i>		<i>VMS Configuration</i>
Trial Nam	VMS Configuration	
Step	Action	Notes
1	Send an SNMP 'get-request' for vmsCharacterHeightPixels.0 vmsCharacterWidthPixels.0 vmsSignHeightPixels.0 vmsSignWidthPixels.0 vmsHorizontalPitch.0 vmsVerticalPitch.0	
2	Verify that these values are in accordance with agency specifications regarding sig dimensions measured in pixels and horizontal and vertical pitch.	
	<input type="checkbox"/> Pass	
	<input type="checkbox"/> Fail	Signature _____ Date _____

Figure 4. Sample DMS Testing Session

Macros

The Exerciser program has the ability to run macros. There is a macro included with the Exerciser program that is titled “NTCIP1203-1.scr”. This macro contains the first three testing sessions and part of the fourth. When executing this macro it is necessary to type the full filename of the macro including the “scr” extension. If this is not done, the Exerciser may terminate and it will be necessary to restart the program.

The power of the Exerciser is contained in macros. There is a document that comes with the Exerciser that explains how to write macros. Creating macros was not addressed in the case study because of the long learning curve involved in learning the macro language.

Conducting a Session

In the WSDOT testing procedure, there are 16 Sessions. Each session deals with a specific part of the object definitions of NTCIP 1203. Sessions 1 thru 3 and the first part of Session 4 are contained in the “NTCIP1203-1.scr” macro. From this point on, manual input is required to conduct the test sessions. This is where the Exerciser fails. The process of conducting a test session of just a few object definitions can require a plethora of mouse clicks and is extremely time consuming. For the case study, there was approximately 40 hours of time put into getting the Exerciser setup and conducting the first four session before the “NTCIP1203-1.scr” macro was discovered that did it all in the matter of seconds. To continue the testing became extraordinarily cumbersome.

Each object definition of each session had to be entered by clicking MESSAGE, SEND on the menu bar at the top of the program window and then EDIT on the screen that pops up. The program will then allow you to browse the object tree.

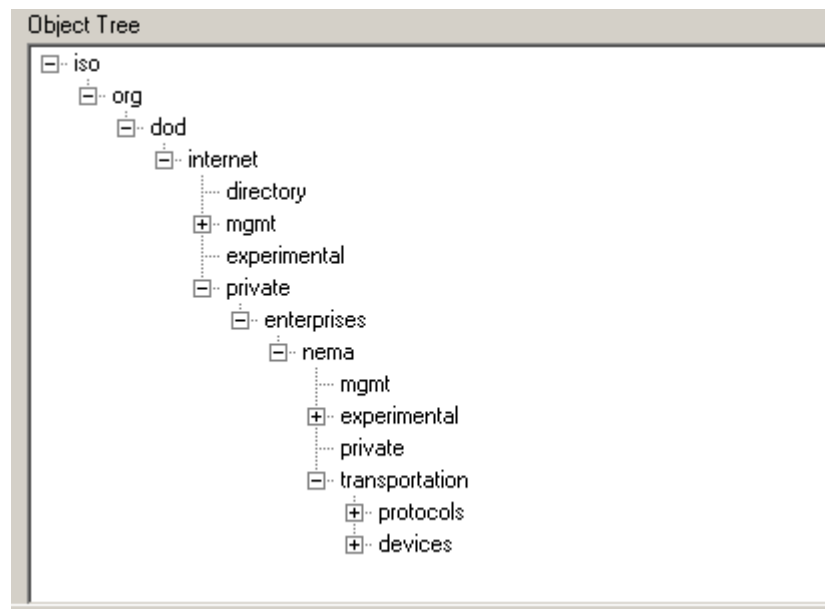


Figure 5. Object Tree

Expand the object tree as shown in Figure 5. Clicking on the “+” next to devices will show a tree for the DMS. All of the object definitions for a DMS are found here.

Select an object definition for the *dmsSignType* and then click add (see Figure 6). It will take some time to find the object definitions in this object tree that you want to add to the session. Once you have added all the object definitions that are in your test session, then you click OK and you are returned to the previous screen. At this point it is a good idea to save the session in case there are any glitches that kick you out of the program. Then make sure the community name and drop address is correct and that screen looks like Figure 7. Now you should be able to click send and send this object definition to the controller. The program will return to the main Exerciser and spit out a series of code and return a series of code. You can now return to MESSAGE, SEND, and then click EDIT. If the value was successfully received, there will be a time stamp and a current value in the box indicated by the yellow arrows in Figure 6. This is how you send and receive object definitions in the Exerciser program and check the results. As you can see from the complexity associated with sending just one object definition, testing a sessions that contains several object definitions will become a very tedious and time-consuming process.

Pass/Fail?

At the end of every test session there is a check box for a Pass or Fail. If the value returned by the controller is correct for the object sent, then the session is passed. To determine if the value is correct, you will need a copy of NTCIP 1201 and 1203, which are available for purchase ITE or NEMA. You can look up the object definition in the applicable NTCIP standard and confirm the result is correct.

CONCLUSION

The case study revealed one very important fact. The Exerciser is too time consuming and too cumbersome to truly be used on an every day basis to test DMSs for NTCIP compliance. An effort needs to be made to streamline this process. The author spent well over 40 hours becoming familiar with the Exerciser program. Granted, this time should become smaller as you get more familiar with the program, but even experts in the field claim it takes 2-6 days to test a DMS using the Exerciser (23). With such a

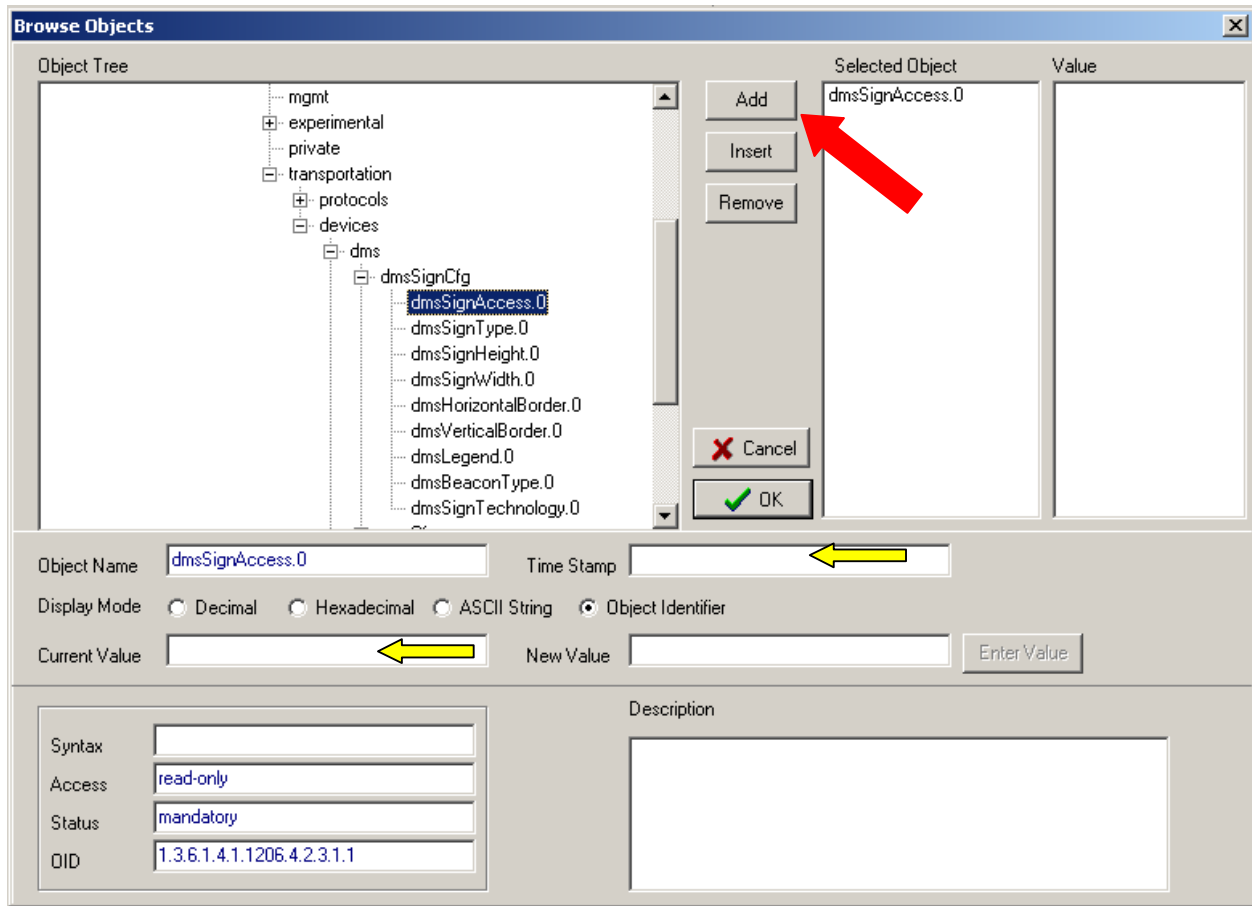


Figure 6. Screen Shot of Selecting an Object Definition

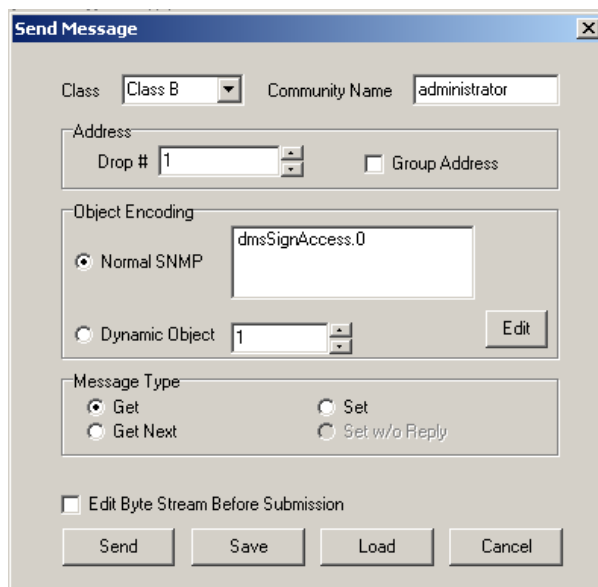


Figure 7. Send Message Screenshot

huge time commitment, it is practically impossible to test every DMS that is purchased. The industry needs to develop a new program that will conduct this test automatically. The TNT and NTester program fix this problem and generally automate the testing process. This is a huge step for the NTCIP testing community.

With the Exerciser program, a considerable amount of time was spent checking COM port settings, experimenting with a null modem, and obtaining the appropriate settings for communication between the computer and the controller. This time should be greatly decreased by simply reading the body of this report. For the NTester, there were issues related to the IP settings for dial-up networking. It appears that a specific port number is needed and no one knew what the number was. A short test was finally conducted using a software program that emulated the controller. In essence, the industry still needs to work out some bugs in simply communicating.

The test procedures that were developed by ENTERPRISE are sound and are a good first step. However, they are almost ready to become obsolete. Version 2 of NTCIP 1203 will be out soon and as a result the testing procedure will need to be modified. The INCH program also shows promise by funding some actual development of practical and useful tools to assist agencies in handling NTCIP. The web site is full of useful tools including a "NTCIP Functional Procurement Specification Guide for DMS" (25). However this specifications guide is outdated because the names of the NTCIP standards were changed. A cross-reference between the old number and new numbers can be found in the NTCIP Guide (26).

The new NTCIP Work Group on Testing and Conformity Assessment needs to be able to overcome some disagreement among NTCIP experts on the matter of testing and provide much needed guidance on exactly what testing should be done and what NTCIP compliant means. If the work group overcomes these obstacles, manufacturers and agencies should fall in line and the testing should become quicker and less difficult.

Because the NTCIP community is generally technology savvy, there is a lot of reference material that can be found on the Internet. This is extremely helpful as NTCIP is young and is still under development. Following any one of the links in this document will lead you to a lot of reference material.

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MARKETING SUPPORT FOR TRANSPORTATION MANAGEMENT CENTERS

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SUMMARY

Transportation Management Centers (TMCs) have become an essential component of today's transportation systems in cities and states across the country. They are usually the main component of an intelligent transportation system which can also include ramp meters, closed circuit TV cameras, loop detectors, and advanced traveler information system to name a few. The TMC often has the daunting task of dealing with rapidly evolving technology, its implementation, and its operation (1). Often, the surrounding community becomes dependent on the new system and can lose faith in a transportation department that does not maintain its functionality.

Obtaining funding for a TMC is not something that is a daily part of the operations of the TMC. The TMC is not a typical construction project that carries the bulk of the cost in the construction, and little to no cost for maintenance. The TMC has constantly changing technology and demand for services. In order to keep up with the demand, a TMC and its partnering agencies need to budget and commit to a viable funding program to cover operations and maintenance after the facility is complete (2).

Increasingly more agencies are realizing that constant communication with legislators and elected officials can lead to an increase in funding and resources (3). One way to begin the communications process is through a simple, informative brochure. The purpose of this research is to create a brochure that will promote a positive self-image of a TMC.

The objectives of this research were to 1) identify individuals and decision makers who are important to the support of a TMC; 2) obtain copies of existing printed materials for TMCs; 3) prepare a set of guidelines for the creation of a brochure; 4) prepare a brochure that will establish the TMC as a successful and valuable product; and 5) determine the effectiveness of the brochure. The scope of the research included current practices of three existing TMCs. Information relating to their background, system components, funding, and current practices of contact with funding sources was collected. Several brochures were then collected and analyzed for their effectiveness based on marketing strategies and a set of guidelines was created. The guidelines were then used to create a sample brochure for a fictitious TMC, which it would use to promote its image to elected officials and decision-makers.

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INTRODUCTION

Transportation Management Centers (TMCs) are increasingly becoming an essential component of the operation of a transportation system within a city. A positive image of the TMC reflecting its vital role in a transportation system must be conveyed to key decision makers and elected officials. Their understanding and support of the TMC is a necessary part of its operation. Some agencies have reported that new funding can derive from better communication with customers including elected officials (3).

Problem Description

Although many major metropolitan areas and even smaller cities may have a TMC, their existence may be experimental or due to the foresight of certain individuals. Other essential individuals may not be aware of the benefits of a TMC. Currently there does not exist a way to inform decision-makers and elected officials of the positive impact that the TMC has on the day-to-day operations of a transportation system.

In order to insure the success and longevity of the TMC, a means of projecting the necessity of the TMC can be created. By the development of a simple, informative brochure, the TMC may have at its disposal a means to inform decision-makers of its benefits. In addition, as new elected officials take office, the brochure will provide the information that will help them become familiar with the TMC.

Research Objectives

The overall goal of this research was to develop a way to project a positive image of a TMC to individuals that are important to its operation. The specific objectives of this research were to:

- Identify the individuals and groups (decision makers) that are important to the support of a TMC by contacting several TMCs;
- Obtain copies of existing printed material for TMCs;
- Prepare a set of guidelines for the creation of a brochure;
- Prepare a brochure that will establish the TMC as a successful and valuable product; and
- Determine the effectiveness of the brochure.

Scope

Literature reviews and interviews provided information from existing TMCs regarding what individuals are important to their operations. Due to space, the research was limited to three existing TMCs. A sample brochure was prepared based on guidelines that used effective marketing strategies. The brochure that was developed was limited to an 8¹/₂-in x 11-in size.

STUDY DESIGN

A work plan consisting of five tasks was developed in order to complete this research. The five tasks are discussed in greater detail in the following section.

Review Literature

A literature review was performed to locate past efforts in the marketing of TMCs. Information on existing TMCs was acquired in addition to information relating to brochure marketing strategies. Sample brochures were obtained and analyzed for their effectiveness.

Conduct Interviews

The TMCs that were included in the research were based on available contacts. A list of contacts was created based on Mentor suggestions and information available from TMC websites. Individuals from three TMCs were contacted and each one responded with information. The three TMCs contacted were Houston TranStar, Georgia Navigator and Minnesota Guidestar. These individuals were contacted either by telephone or by email. Sample questions that were asked are available in Appendix A. The objectives of the interviews were to:

- Determine the source of funding for the TMC;
- Identify if there was regular contact with the funding source;
- Obtain printed materials if available; and
- Determine if they felt that the TMC communicated adequately with elected officials in their area.

Review and Analyze Sample Brochures

Five sample brochures were obtained from transportation agencies. These brochures were first reviewed by the author to determine which ones appeared more effective. The brochures were then analyzed based on brochure marketing strategies. The author's review of the brochures seemed to coincide with the ranking based on marketing "rules". Based on the marketing rules and the needs of TMCs, a set of guidelines was created.

Develop Guidelines for a Generic Brochure

A series of guidelines were created which could be followed to create a brochure for a TMC. Initially, the information needs of elected officials were obtained based on a study done by the Texas Transportation Institute (TTI) (4). Next, a set of rules was created based on effective brochure marketing strategies. Finally, the two were combined to create a set of guidelines that a TMC could use to project an effective, positive image to an elected official or decision-maker.

Create a Sample Brochure

The guidelines were applied to create a brochure for a fictitious TMC. The sample brochure was created to show how the guidelines could be applied.

Determine Effectiveness of Sample Brochure

The sample brochure that was created using the guidelines was sent to several individuals for comment. The individuals were sent a copy of the brochure with an explanation of the rating system to be used to score the brochure.

EXISTING TRAFFIC MANAGEMENT CENTERS

The following three TMCs were chosen for this research based on available contacts and time. There are many other TMCs in existence; however, the duration of the research period limited the time available to contact additional TMCs.

Houston TranStar

Overview

Houston TranStar is a 52,000 sq. ft. Transportation Management Center that is responsible for the management of transportation operations and emergency services for the Greater Houston area (5). The TranStar building houses four different agencies, the Texas Department of Transportation, City of Houston, Harris County, and the Metropolitan Transit Authority of Harris County (METRO).

Components

In order to manage the variety of freeway and arterial streets within the Greater Houston area, TranStar utilizes (5):

- 160 Mile Freeway Management System
- Freeway and Arterial Street Incident Management
- Flow Signals at 103 Ramps
- 257 Closed Circuit TV Freeway Cameras
- 100 Variable Message Signs
- Motorist Assistance Program (MAP)
- 86.4 Mile HOV Lane System
- Regional Traffic Signals System (2,800 Signals)
- ITS Programs
- Emergency Management Operations
- Flood Alert System

Funding

Each agency contributes to the annual operating budget of the Center on a prorated basis relative to their occupancy and utilization of building components (5). There are three levels in the management structure at Houston TranStar. The Executive Committee sets policy and decides fiscal matters. The Leadership Committee coordinates staffing, and the Agency Managers Committee oversees daily operations. A recent study done by TTI (4) included a survey of community and transportation leaders in an attempt to determine what their expectations were for TranStar. Among the comments was the need for an outreach program. Currently, most of the contact with elected officials is during press conferences or media events (6). Houston TranStar is currently updating their vision statement that includes "promoting regional communication and enhanced awareness of Houston TranStar services" (4).

Georgia NAVIGATOR

Overview

Georgia's Transportation Management Center is at the heart of their intelligent transportation system known as NAVIGATOR (7). It is a 73,500 sq. ft. building located in Atlanta which also houses the Georgia State Patrol and the Georgia Emergency Management Agency (GEMA).

Components

NAVIGATOR links together the TMC with the Transportation Control Centers (TCCs), the City of Atlanta, and the Metropolitan Atlanta Rapid Transit Authority (MARTA). It uses the following components in its daily operation (7):

- Transportation Control Centers (TCC) in 5 Counties
- 67 Color TV Cameras With Pan, Zoom, and Tilt
- 300 Fixed Black-and-White Cameras
- Gyroscopic Helicopter Mounted Camera
- More than 45 Changeable Message Signs
- 24 Hr Traffic Information Service
- Highway Emergency Response Operators (HEROs)
- Motor Vehicle Emergency Response Team (MoVER)
- Accident Investigation Sites
- Traveler Information Kiosks

Funding

Costs associated with personnel compensation, power, communications, and operating expenses are covered by federally funded projects with an 80% federal, 20% state fund split. Correspondence with Mr. Marion Waters of the Georgia Department of Transportation indicated that the TMC could improve its communication with elected officials to inform them of the operations of the center (8).

Minnesota Guidestar

Overview

Minnesota's Guidestar is the state's intelligent transportation system (ITS) program (9). At the center of that system is the TMC that began its operations in the early 1970s.

Components

The various components of Guidestar include:

- 230 Closed Circuit TV Cameras along 210 miles of Metro Freeway
- 60 Variable Message Signs
- 430 Ramp Meters
- 3700 Loop Detectors
- Highway Helpers - Assist in removing stalled vehicles
- ITS Projects
- Traveler Information Program
- High Occupancy Vehicle (HOV) System
- Incident Management Program
- Research and Development

Funding

The Traffic Management Center obtains funds for design, operations and maintenance staff from state funds (10). Correspondence with Mr. Glen Carlson has indicated that in general the TMC has been successful in funding the program. However, during the 2002 session, the state legislature failed to provide long term transportation funding. Lack of funding has caused MnDOT to cancel or delay construction projects. It could also mean that federal transit dollars for commuter light rail will not go to Minnesota, but to other states that are able to provide matching funds (11). The Guidestar Board of Directors created the ITS Strategic Plan 2000 in which they outlined a goal to expand ITS outreach and education efforts including policymakers and legislators.

CREATING AN EFFECTIVE BROCHURE

Brochures can be a useful tool to increase communications and there are several ways to make them more effective. The following rules were created by the author based on suggestions from two marketing websites. (12,13)

Keep the Cover Simple

The cover should contain a clear concept without too much clutter. Do not try to do too much on the cover, or it will confuse the reader.

Communicate your Purpose

State in the beginning what is the purpose of the brochure. Make the brochure easy to read with concise, clear paragraphs.

Use Sub-headlines

Sub-headlines break up the text and further explain your message. They can be in the form of questions or emphatic statements (13). They should simplify the text so that the reader will have an understanding of the material even if they do not read the entire brochure.

Deal in Spreads not Individual Pages

A spread is different from a page by page layout because the information is not broken up by the folding lines of the brochure. Laying out the information in spreads gives the opportunity for more options in design and text layout. Using the "spread" means letting graphics or text start at one end of the brochure and continue to the other end. Therefore, instead of confining material to individual pages it can extend across the whole brochure.

Use Selective Emphasis

Selective emphasis implies that certain items within the brochure should stand out from the rest of the document. However, be careful not to try to emphasize everything because "in a room full of shouting people, one more shout is unlikely to stand out." (12).

Use Contrast

Visual contrast can be added by using white space, fonts style and font size. In addition, size of graphic objects can be varied to emphasize one over another.

Don't Overdo Colors and Fonts

With many choices of colors and font styles, it is easy to overuse them. The best brochures use a minimal amount of colors and color effects (12).

ANALYSIS OF SAMPLE BROCHURES

Five transportation-related 8¹/₂-in x 11-in brochures were collected from transportation agencies and reviewed. Each one was ranked by the author from one to five based on initial appeal, overall look, and effectiveness at communicating its message. A ranking of five indicated a "fair" brochure and a ranking of one indicated the best brochure. Next, each one was scored based on the marketing rules summarized above. Table 1 was created to illustrate the scoring of the brochures based on the rules. If the brochure

followed the rule, it was given a score of one, and if it did not, it was given a score of zero. The scores were then tabulated to give each brochure a final score from zero to seven.

As shown in Table 1, the ranking of the brochures by the author is very similar to their scores based on the marketing rules. Therefore, the scoring system based on the marketing rules can be used to create an effective brochure.

Table 1. Score of Sample Brochures

Brochure number	<u>Rule 1</u> Keep Cover Simple	<u>Rule 2</u> Communicate Purpose	<u>Rule 3</u> Use Sub- headlines	<u>Rule 4</u> Use Spreads	<u>Rule 5</u> Use Selective Emphasis	<u>Rule 6</u> Use Contrast	<u>Rule 7</u> Don't Overdo Colors and Fonts	Final Score
1	1	1	1	1	1	1	1	7
2	1	1	1	0	1	1	1	6
3	1	1	1	1	1	1	1	7
4	0	0	0	0	1	1	1	3
5	0	0	0	0	0	0	1	1

BROCHURE GUIDELINES

The following guidelines were created based on the previously listed marketing rules applied specifically for the creation of a brochure to successfully market a TMC to elected officials.

Guideline 1 - Keep the Cover Simple

Display the title of your brochure, and possibly a graphic for added interest. It is also a good idea to have your TMC logo on the cover to add association to it.

Guideline 2 - Communicate your Purpose

Create your brochure with a specific audience in mind. For example, elected officials are concerned with costs and benefits to their jurisdictions (*14*), and that should be included in the brochure.

Guideline 3 - Use Sub-headlines

Sub-headlines that break up the text can make the brochure easy to read. You want to get your point across as quickly and easily as possible. Do not use long paragraphs of text or your reader will lose interest.

Guideline 4 - Use the Brochure Area to Your Advantage

The brochure, when open, is an 8¹/₂-in x 11-in piece of paper. Use it! Text does not have to be confined to the folding lines.

Guideline 5 - Don't Emphasize Everything

If you capitalize all the text, nothing will stand out. Highlight either the sub-headlines or pieces of the text that are important, but not everything.

Guideline 6 - Use Contrast, But Don't Overdo it

Using white space, differing font type, and font sizes can add contrast, but be careful not to overuse them.

Given the above set of guidelines, a simple effective brochure can be created. It can be tailored to the elected official or decision-maker and project a positive image of the TMC. Using the brochure as a means of communication may be one way to emphasize the importance of the TMC and secure funding at the federal, state, and local levels (2)

APPLICATION OF GUIDELINES TO CREATE A BROCHURE

The previously outlined guidelines were used to create a brochure for a fictitious city's TMC. A copy of the brochure can be found in Appendix B. The brochure is specifically marketed towards elected officials and decision-makers. The name of the fictitious city is Futuro and their TMC system is known as GoTrans.

The brochure is a three-fold 8¹/₂-in x 11-in size brochure that a GoTrans would distribute to legislators who will vote on transportation funding in the next session. The brochure follows each of the previously mentioned guidelines as follows:

Guideline 1 - Keep the Cover Simple

The logo "GoTrans" is displayed on the cover along with the purpose of the brochure.

Guideline 2 - Communicate your Purpose

The purpose of the brochure is to inform legislators of the benefits of GoTrans and the need for funding.

Guideline 3 - Use Sub-headlines

There are no long paragraphs, and text is broken up by subheadlines such as "Benefits of GoTrans".

Guideline 4 - Use the Brochure Area to Your Advantage

The spread of the brochure is used to the TMC's advantage, and text is not confined to folding lines. This allows for more options when placing graphics and making statements such as the one across the bottom of the brochure.

Guideline 5 - Don't Emphasize Everything

Some text is underlined and some is boldface, which emphasizes important items. The text at the bottom of the brochure is enclosed in a box to add emphasis.

Guideline 6 - Use Contrast, But Don't Overdo it

The font type is consistent throughout the brochure and white space is used for contrast.

BROCHURE EVALUATION

Once the sample brochure was complete, it was sent out for comments. The author contacted individuals with The Texas Department of Transportation (TxDOT), TTI, and the Federal Highway Administration (FHWA) TMC Pooled Funds Group. Each person received a copy of the sample brochure and instructions relating to the scoring system. They were then asked to score the brochure and provide any additional comments.

Scores that the sample brochure received were five, six, and seven out of a possible seven. The high scores that the brochure received indicated an effective brochure. The comments that were received regarding minor changes were made, and the revised brochure is shown in Appendix C.

CONCLUSIONS

Transportation Management Centers are increasingly becoming an important component of major city and state transportation systems. Historically, transportation spending has focused on new construction; however recently, intelligent transportation systems (ITS) have been the focus. Many state departments of transportation (DOTs) have increased demands for transportation services and new technologies (3). Increased functions and technologies lead to an increase in spending, but taxpayers are not always willing to spend more. DOT's and specifically TMCs need to make key decision makers aware of TMC programs, systems, benefits, and costs. Several DOTs have seen an increase in funding due specifically to promoting their image to legislatures (3).

By using a simple brochure, TMCs can begin to communicate with elected officials and decision-makers and secure the funding needed to continue to expand and maintain their systems. As terms expire and new officials take office, the brochure can be circulated to insure that the effectiveness and necessity of the TMC is well understood.

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APPENDIX B

Did you Know?

Land Use

GoTrans' daily operations are an essential part of the way we travel. Every year as more vehicle miles are added to our roadways, **managed lanes reduce the need to add more lanes and expand our right of way.**

Air Pollution

Air pollution is everyone's concern, and at GoTrans we help alleviate it. HOV lanes, fuel efficient transit vehicles, and our new light rail system have **improved our city's air quality rating.**

GoTrans



YOU can make a difference today!

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Support

GoTrans

Keep Our City Moving Into The Future!



Figure 1. Sample Brochure - Outside



Benefits of GoTrans

- Reduced Congestion
- Reduction of harmful emissions
- Fast response to incidents
- Emergency management
- Highway Advisory Radio
- Advanced Traveler Information Systems
- Commuter light rail

Increased funding means:

- Reduced commute times
- Updated real-time traffic information
- Faster, safer removal of incidents
- Addition of closed circuit TV cameras
- Better signal timing coordination
- Addition of light rail to downtown
- Construction of additional HOV lanes

Last year the number of vehicle miles traveled in metro Futuro increased by 10%. To keep up with the demand for transportation we need to continue moving GoTrans into the future! You can help us do that by **supporting future GoTrans funding**. We have a great system in place, but as we grow we need to expand and maintain it.

Your Support Will Help Us Continue to Do What We Do Best...Keep Futuro Moving!

Figure 2. Sample Brochure - Inside

APPENDIX C

Did you Know?

Land Use

GoTrans' daily operations are an essential part of the way we travel. Every year as more vehicle miles are added to our roadways, managed lanes reduce the need to add more lanes and expand our right of way.

Air Pollution

Air pollution is everyone's concern, and at GoTrans we help alleviate it. HOV lanes, fuel efficient transit vehicles, and our new light rail system have helped improve our city's air quality rating.



YOU can make a difference today!

Contact Information:

Futuro TMC Traffic Engineer:

Carissa M. Mardiros

Phone: 561-234-5678

Email: engineer@futuro.com

Website: www.gotrans.com

Support



***Keep Our
City
Moving
Into The
Future!***



Figure 3. Revised Sample Brochure - Outside



Current GoTrans Functions:

- Emergency management
- Highway Advisory Radio
- Advanced Traveler Information Systems
- Commuter light rail

Support for GoTrans means:

- Improved commute times
- Updated real-time traffic information
- Faster, safer removal of incidents
- Addition of closed circuit TV cameras
- Better signal timing coordination
- Addition of light rail to downtown
- Construction of additional HOV lanes

Last year the number of vehicle miles traveled in metro Futuro increased by 10%. To keep up with the demand for transportation we need to continue moving GoTrans into the future! You can help by **supporting future GoTrans funding**. Futuro has a great system, but as Futuro grows, expanding and maintaining it will require your support.

Help Us Continue to ... Keep Futuro Moving!

Figure 4. Revised Sample Brochure – Inside

CARISSA M. MARDIROS



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INTEGRATION AND APPLICATION OF HIGHWAY ADVISORY RADIO TO THE TRANSGUIDE TRAFFIC MANAGEMENT CENTER

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SUMMARY

San Antonio has been growing rapidly resulting in an increase in construction activities. Many commuters are traveling to San Antonio from smaller communities outside the area. Presently there are no Traffic Management devices available for these commuters on most of these routes. Once in the metropolitan area, these commuters receive valuable traveler information through Lane Control Signals and Dynamic Message Signs.

The Texas Department of Transportation proposes Highway Advisory Radio as the means of transmitting valuable information to these commuters outside the metro area. A literature review along with interviews with various agencies was conducted to acquire a better understanding of the function and operations of these systems.

Based on the literature and interviews, the author proposes a design of a conceptual system and typical messages that may be broadcast for the TransGuide Traffic Management Center. The conceptual and message designs encompass the areas of text-to-speech software, integration, diagnostic features, system architecture and design cases for typical messages from route diversion to travel time.

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INTRODUCTION

Currently San Antonio is undergoing major roadway improvements over the next 5 years. Substantial reconstruction will occur on interstate highways in and around the area. Information displayed on Dynamic Message Signs (DMSs) provide valuable information for travelers in the metropolitan area, however; there is a need for commuters and long-haul North American Free Trade Agreement (NAFTA) truck traffic entering the metro area to receive this information where DMSs do not exist.

The Texas Department of Transportation (TxDOT) plans to deploy a Highway Advisory Radio (HAR) system in at least two places on major interstate highways at suitable locations to serve the traveling public approaching the city. The locations for deployment of the HAR systems will be chosen by TxDOT to provide useful and effective traveler information reflecting current delays.

TxDOT plans to integrate the HAR capability into the TransGuide™ Traffic Management Center (TMC). More specifically, text messages entered by the TMC operators will be broadcast on the HAR system through the use of Text-To-Speech (TTS) technologies.

Problem Statement

Many districts in the TxDOT organization are constructing TMCs. Automation and current Intelligent Transportation System (ITS) technologies are being utilized to establish more efficient TMCs. Experience shows that most HAR systems require a small staff to operate efficiently. TransGuide does not have the resources to adequately staff an efficient HAR system. Therefore, the TransGuide TMC desires to take advantage of the TTS software that can be integrated into the TransGuide operating system.

Research Objectives

The overall goal of this research is to propose recommendations for an effective implementation and application of the HAR system to the TransGuide TMC. To reach a confident set of recommendations a series of tasks will be systematically undertaken. These tasks are the following:

- Identify the techniques other transportation agencies are using to integrate HAR systems;
- Determine the benefits and limitations of previous deployments;
- Identify and evaluate information needs and preferred methods of attracting the attention of the traveling public;
- Investigate translating text messages into voice systems that could be used for HAR;
- Design a set of HAR messages and the translation approach for use by the TransGuide TMC; and
- Develop recommendations that can be used by TransGuide TMC.

Scope

This research is limited to operation and integration of existing HAR systems established by various transportation agencies in the nation. It does not focus on the communications, utilities, cost, or FM bandwidth available for these systems but may touch on these areas as part of preparation.

Organization of Report

The literature review for this paper extends through the Background, Federal Communication Commission Requirements, HAR Systems and Uses, and Message Development. The Background section provides history and general information on HAR systems. Provisions for HAR systems are summarized in the Federal Communication Commission Requirements section and equipment, advisory signing, and traveler information are discussed in the HAR Systems and Uses section. The Agency

Experience section contains the results of interviews as well as the techniques transportation agencies are using to operate HAR systems, also the benefits/limitations of deploying these systems. Message format, repetition, and use of trailblazers are included in the Message Development section, and based on the above-mentioned sections; a suggested process for integration and HAR message designs are proposed in the Text-To-Speech Technologies and Proposed Integration of HAR section. Lastly, Conclusions and Recommendations are offered to the TransGuide TMC.

BACKGROUND

HAR is one of the oldest traveler information technologies available in the ITS industry. HAR was first used in 1940 on the George Washington Bridge in New York and has expanded considerably (1). These systems typically provide information about current traffic conditions, travel restrictions, notices of events, and general safety information. HAR restrictions and systems must be understood in general before one can develop recommendations applicable to the TransGuide TMC.

The widespread use of HAR systems has generated a great deal of information on how to operate HAR effectively. Of foremost importance is meeting motorists' expectations. An FHWA study suggests that drivers will not place faith in a system that (2):

- Broadcast information contrary to existing conditions;
- Broadcasts information that is not understood or cannot be heard in time to make appropriate maneuvers;
- Recommends a course of action that-in the motorists' perception-is not significantly better than their intended action; or
- tells them something they already know.

Such updates are only possible with sufficient personnel.

FEDERAL COMMUNICATION COMMISSION REQUIREMENTS

The Federal Communication Commission (FCC) is an independent United States government agency, directly responsible to Congress. The FCC was established by the Communications Act of 1934 and is charged with regulating interstate and international communications via radio, television, wire, satellite and cable. The FCC's jurisdiction covers the 50 states, the District of Columbia, and U.S. possessions (3).

In the *Highway Travelers Information Stations and Highway Advisory Radio* document, the FCC Rules & Regulations – section 90.242, are summarized for HAR systems (4).

HAR Candidates

HAR systems may only be licensed to governmental entities. Non-governmental organizations may operate the systems, but only under the purview of the licensee. The licensee is ultimately responsible for the system's proper operation.

Frequency Availability

As of April 19, 1992, the FCC implemented changes with respect to the entire Amplitude Modulation (AM) band including one which allows HAR radio stations to be licensed for operation on any open frequency from 530 kHz to 1700 kHz. Prior to then, stations could only be licensed on either 530 or 1610

kHz. This change will allow the location of stations in areas that previously were precluded from having a system because of frequency conflicts.

Secondary Basis Operation

HAR stations operate on a secondary basis to commercial radio stations. There are specific limitations regarding proximity and frequency spacing between the two. If a new commercial station goes on the air, or an existing station moves thereby creating a frequency conflict, the HAR system must make adjustments to eliminate the conflict. No grandfather clauses will be considered in these cases. In the event of such an occurrence, the easiest way to eliminate the conflict is to change the frequency of the HAR system and amend the license accordingly.

Legal Use

HAR systems may transmit non-commercial voice information about traffic and road conditions, traffic hazards and travel advisories, directions, availability of rest stops, lodging and service stations, as well as descriptions of local points of interest.

In the case of airport, train and bus terminals, it is permissible to announce the trade names of carriers to facilitate announcements concerning departures and arrivals as well as information about parking areas.

Illegal Use

HAR systems may not be used to transmit music or to identify the commercial name of any business establishment whose services may be available within or outside the coverage area of the station. For example, it is not permissible to say "restaurants at the next exit include "X" and "Y," but is permissible to say, "there are two restaurants and one motel at the next exit."

HAR and the National Association of Broadcasters

When HAR stations were first authorized in the late seventies, the National Association of Broadcasters (NAB) expressed concern about the potential for competition. For instance, if a restaurant could advertise on a governmental station, arguably commercial stations might lose potential advertising revenue. To ameliorate this concern, the FCC prohibited advertising on the HAR stations.

Concern also grew that HAR systems would broadcast music thereby eroding commercial stations' share of the listening audience. To address this concern, the FCC did two things. They prohibited the playing of music, and they limited the quality of the audio to a maximum of approximately 3.5 kHz.

Operational Limitations and Equipment Restrictions

The energy from HAR systems is limited in two ways. Maximum transmitter RF output power is 10 watts. Additionally, field strength is limited to 2mV/m at a distance of 1.5-km (.93 miles) from the antenna. In most cases, the 2 mV/m field strength can be achieved with less than 10 watts of power, so field strength is generally the more restrictive limitation.

The tip of the antenna may be a maximum of 15 meters (49.2 feet) above the ground. This is especially important for those planning rooftop mounted systems. This requirement usually limits mounting to buildings no more than two stories tall.

FCC License Procedure

To obtain a license for the HAR station, one must file a Form 574 with the FCC. In addition, licensees are required to submit maps showing the proposed station's 2mV/m contours and to identify adjacent commercial stations within the region.

Once the FCC receives the application, a file number is attached and processing proceeds. It normally takes the FCC about two weeks to assign the file number and about 90 days to complete the review process. A permanent license is issued for a five – year term and must be renewed at the end of that period.

The FCC understands that some stations are installed for public safety reasons and acknowledges that this processing delay may impact safety. A procedure exists to grant a licensee Special Temporary Authority (STA) to go on the air while the formal review process is being completed. After a file number is assigned, the licensee may apply for the STA. The FCC will respond within 10 days either approving or disapproving the temporary authority. The STA lasts for six months and must be renewed if a permanent license has not been issued within that period.

There are two types of permanent licenses available. One is for fixed and the other for mobile operations. The fixed-site license specifies the exact location of the antenna. The mobile license is issued for a region of operations.

In the case of mobile stations, the licensee still has the obligation to operate in a manner that does not conflict with commercial radio stations or with other fixed site HARs.

Exceptions

The regulations are explicit, although there are exceptions. HAR systems were originally developed to serve in the public's best interest. To fulfill that mission, circumstances sometime dictate a need to operate in a different manner than the regulations allow.

The FCC will consider requests for variances; however, there must be compelling reasons for such a request, and approval is not guaranteed. The FCC will carefully consider the public's interest as well as potential conflicts with other licensees.

HAR systems may utilize a series of low-power, 0.1-watt transmitters that are interconnected and synchronized to form a zone of coverage. Low-power transmission does not require FCC licensing and can be broadcast over any unused commercial radio frequency. The major advantage of low power transmission over 10-watt transmission is that transmitters can be arranged in a customized zonal configuration, allowing unique messages to be broadcast in each zone as opposed to the 10-watt transmitters which broadcast radially outward (5).

HAR SYSTEMS AND USES

Equipment

HAR systems can broadcast information 24 hours a day and generally transmit low-power AM radio signals. These systems may use either a fixed-site antenna or portable field antenna. Each system primarily has four components: an audio source, a transmitter, an antenna, and a ground system (1,4).

Audio Source

Most systems employ a digital recorder as the primary audio source. The digital recorder performs essentially the same functions as the tape recorder with the exception that magnetic tape has been replaced by solid-state memory as the recording medium. Most of the logic that determines how a system operates is in the digital recorder (4).

The digital recorder stores and replays messages in a continuous loop. Messages usually last for one to three minutes before recycling. Ideally, a motorist should be able to hear two complete cycles while passing through the broadcast zone (6).

Transmitter

The transmitter transforms a basic audio system into a broadcasting radio station on the AM band.

Transmitters come in various Classes of service. A transmitter's Class refers to its power-amplification stage, and suggests both the stage's mode of operation as well as its efficiency. The more efficient a transmitter, the less power it requires to operate and the less heat it generates while in operation (4).

Antenna

Antenna systems for HAR are typically vertical monopole antenna (Figure 1) or cable antenna. Vertical monopole antennas are more commonly used and can generate signals that are intelligible from 3-8 miles, depending on the transmitter used. One HAR system manufacturer also suggests that broadcast range can vary greatly with topography, obstructions such as trees, buildings, or power lines in the area, geology, and soil type for conductivity. Cable antennas are either buried or hung along the roadway and consist of two main types: radiating and "leaky". Radiating cable antennas are restricted to 1.86-mile runs over which the message is heard. The "leaky" antennas, unrestricted in length, radiate a weak signal just strong enough to be detected along the length of cable. The primary advantage of cable antennas over vertical antennas is that in areas where the signal is weak, such as in tunnels, cable antennas can be used within the tunnel to broadcast messages. Disadvantages of cable antennas are that maintenance and installation costs (trenching) are considerable. Furthermore, cable antennas are susceptible to disconnects due to construction activities or corrosion by water (4,5).



Figure 1. Vertical Monopole Antenna (7)

Ground System

Unlike Frequency Modulation (FM) radio which travel by line of sight, AM follows the curvature of the Earth. Proper grounding is essential for AM stations to achieve maximum performance. A ground system is an array of conductive wire, generally copper, located below the ground, usually at the base of the antenna. In addition to propagating radio waves along the Earth's surface, a properly installed ground system reduces the risk of equipment damage due to lightning (4,8).

Radio energy is propagated by both surface and space waves. The surface wave travels along the surface of the Earth while the space wave travels through the atmosphere. Both are important in achieving maximum broadcast performance. The space wave is a function primarily of the antenna's efficiency and height. The surface wave is primarily a function of the Earth's conductivity and proper grounding of the radio system (4).

Advisory Signing

Because the broadcast range is limited, it is important for motorists to be tuned to the station as much of the coverage area as possible. Successful operation of an HAR system is in part affected by the advanced sign. Failure of the motorists to read the sign will affect the size to the audience. Several agencies have a policy of placing an advance sign 1.6 km (1 mile) outside the coverage zone, so all motorists have time to tune in before the broadcast begins. Considering the equipment now available in most automobiles, motorists are able to tune to a station in considerably less time than 60 seconds. As a result, the practice of installing advisory signs with the station's frequency 1.6 km (1 mile) outside of the coverage area may be ineffective, and the first advisory sign which includes the station's frequency should perhaps be located much closer to, or perhaps within, the coverage area (2,9).

A study was conducted in New Braunfels, Texas during the annual Wurstfest Festival. The event attracts people from several cities in Texas. An HAR system was used to divert Wurstfest traffic to a less congested route. Table 1 shows the proportion of Wurstfest-bound drivers interviewed who saw the advance sign during the two-day study.

Table 1. Wurstfest-Bound Drivers Who Saw Advance Sign (9)

Date	Number of Interviewed Going to Wurstfest	Interviewed Drivers Who Saw Advance Sign	
		Number	Percent
November 3rd	260	161	62
November 10th	102	49	48
TOTAL	362	210	58

Drivers were asked to cite the reasons why they did not tune to the radio station. The combined data from both study days reveal that a high percentage of the drivers who did not tune to the station after reading the advance sign were simply apathetic toward the system. Forty-two percent indicated a degree of apathy; 19 percent preferred to listen to the music they were tuned to on their radios; 15 percent stated that they did not need the information; and 8 percent did not want to tune to the HAR station. Only 11 percent stated they did not understand the message on the advance sign. Thirty-seven percent offered no reason. The use of flashing beacons on the sign perhaps may have resulted in better target and attention characteristics on both days (9).

Static Sign with flashing beacons

Signs should be clearly marked with the appropriate frequency and as few words as possible. Letter height should be correct for the designated driving speed. Guidelines for sign construction along most highways are specified in the Manual of Uniform Traffic Control Devices (MUTCD). Colors must be appropriate to indicate important motorist information—usually blue for tourism and brown for historical events. These signs can be manufactured with flashing beacons and are usually activated when HAR operators broadcast a critical message. Figure 2 illustrates a static sign with flashing beacons.



Figure 2. Static Sign With Flashing Beacons (10)

Dynamic Message Sign

DMSs are another strategy used as advisory signs. They can also relay situation-specific information, so drivers can decide whether to tune in based on their perceived need for the information. For example, a general message such as “TRAFFIC ADVISORY” could be changed to “ACCIDENT,” “TOURIST,” “ALERT”, or “DETOUR INFORMATION,” depending on the situation (2). Figures 3 and 4 show examples of what types of messages might be displayed.



Figure 3. DMS “TRAFFIC ALERT” Advisory Sign



Figure 4. DMS “DETOUR INFORMATION” Advisory Sign

Traveler Information

Many transportation agencies use HAR broadcasts to inform travelers of (L):

- detours;
- operating restrictions such as requirements to put on snow tires or chains;
- warning about hazards such as forest fires, floods, mudslides or highway closures;
- traffic conditions along short segments of specific routes, especially work zones;
- parking availability;
- public transit alternatives; and
- notices of events.

AGENCY EXPERIENCE

Transportation Agencies were contacted for interviews in order to learn what practices are used in each state and to assess their effectiveness. State agencies that have HAR systems in rural and urban areas were targeted. Of the eight agencies contacted, five responded for interviews. Table 2 contains a list of the people interviewed and Appendix A list sample interview questions asked of each agency. This section summarizes the information from interviews and other literature sources.

Table 2. Interview Contacts

Name	Organization
Glen Carlson	Minnesota Department of Transportation
Robert Dale	New Jersey Turnpike Authority
David E. Fink	Texas Department of Transportation
Michael Gousse	Washington State Department of Transportation
Tim McGary	Wyoming Department of Transportation
Ted Wells	Wyoming Department of Transportation

State Practices

Common practices are used by many of the state agencies surveyed. All state agencies agreed that the importance of keeping the messages current is extremely important. The creditability of the system is compromised when listeners tune in to find a message that is outdated. Furthermore, and with the

exception of the Wyoming Department of Transportation, the operations of the HAR systems are located in their respective TMC. In addition, many of the state agencies use portable HAR systems in construction areas or special events.

Minnesota (11)

Since 1988, Minnesota's Department of Transportation (MnDOT's), Metro Division in the Minneapolis/St. Paul area utilizes a unique partnership with the Minneapolis Public School System. KBEM – 88.5 FM is the radio station owned, operated and maintained by the public school system; however, during peak periods MnDOT broadcast traffic information every 10 minutes. In the event of a major incident, during peak or off-peak periods MnDOT broadcast continuously until the incident clears.

Crashes, congestion, work zone lane closures, and incidents such as stalls, pavement failures, flooded roads, and spilled loads are specific applications applied by MnDOT. Most of the reports are on the urban freeway network, but traffic information can also be provided on arterial streets and only when reports can be confirmed.

MnDOT promotes KBEM Traffic Radio by means of brochures, traffic web-site, the DMSs (only when there is a major incident), tours, presentation, and during media interviews. In the past static signs with wigwag flashers, which were activated during incidents, were used to inform motorists of the service, but have since been removed.

The messages are broadcast live and in real-time from the TMC. Surveillance information from vehicle detection devices, Closed Circuit Television (CCTV), and State Patrol 911 calls, makes broadcasting traffic information most effective from the TMC location. Broadcasting from the TMC also enhances the coordination of all the incident management activities.

The advantage of the Traffic Radio service provided on KBEM is that it offers good quality broadcasts throughout the Twin City Metro Region, (approximately 30-mile radius) and does not leave a lot of infrastructure to maintain. It also avoids the work required with tapes, and some of the broadcast quality issues that the 10-watt HAR systems have. The disadvantage, however, is that the service broadcast the same information region wide and cannot be transmitted in a localized area similar to that of a typical HAR system.

Annual market research studies, informal feedback via telephone, written correspondence, and e-mail are used in measuring the effectiveness of the service. Observations from the TMC can confirm that motorists are diverting to alternate routes when it is recommended that they do so during the broadcasts.

New Jersey (12)

The New Jersey Turnpike Authority introduced a HAR system in July of 1992. The HAR system functions on 1610 kHz and 530kHz and provides motorists with the latest, up-to-the-minute reports on road and traffic conditions along the entire length of the roadway. The system remains on the air 24 hours a day, seven days a week, 365 day a year. Whenever possible, traffic conditions on surrounding roadways and facilities are also broadcast (13).

The system provides information on:

- Current traffic conditions;
- Travel restrictions;
- Notices of events throughout New Jersey;
- Directions to popular tourist attractions; and
- General safety information.

The HAR system is updated for accidents, congestion, construction and special events. During non-emergencies, broadcast messages include information about safety, points of interest, driving tips and service area information as a public service (13).

Nine fixed and two portable transmitting sites comprise the HAR network. Static signs have been placed strategically along the roadway and are equipped with flashing beacons. In the event there is an accident, congestion, or lane closures; the lights are activated to alert motorists that an urgent message is being broadcast.

The messages are broadcast from a central Traffic Operations Center (TOC), assuring that the traffic information is timely as it is delivered from the roadway. The only limitation for having the HAR operations in the TOC, is space. The facility was not designed for the systems' current use.

The broadcasts use both pre-recorded "canned" and recorded messages. The quality of the transmission and radius are dependent on the area and the neighboring frequencies the messages are being broadcast.

The New Jersey Turnpike Authority can verify the usefulness of the HAR system once messages on lane closures and route diversions are broadcast. Results can be viewed through the use of the CCTV(s) or through reports from toll collectors, maintenance personnel, operations supervisors and the state police.

Texas (14)

The Houston District of TxDOT just recently installed 12-fixed units at various locations around the Houston/Galveston area. In December of 2001, six units were placed on the I.H. 610 Loop, one on the Galveston Causeway, two on the Eastside of Houston and an additional three in rural areas. In the event that there are no incidents, TxDOT has the option to broadcast weather information from National Oceanic and Atmospheric Administration (NOAA) on their system. Messages are either broadcast on frequencies 1610 or 1630 kHz and offers the motorist information on major accidents and construction. TxDOT also uses a portable HAR unit utilizing both frequencies. Construction and special events, such as the Houston Livestock and Rodeo, allow TxDOT to use this unit effectively.

TxDOT is currently installing flashing beacons to existing static signs and using DMSs to attract the motorist to tune to the broadcasts in the event there is a major incident. A paging system will activate the beacons when an urgent message is being broadcast.

The operation of the HAR system resides at the TxDOT TMC in Houston, but since the system is fairly new, information on the effectiveness has not been recorded. The quality of the transmission is dependent on the surrounding features, and TxDOT is presently working out some interference issues with a radio station in Monroe, Louisiana.

Washington (15)

In 1996 the Washington State Department of Transportation established an HAR system in their South Central Region. Listeners tune their radio to frequencies 530 and 1610 kHz AM for current up-to-date road and weather information. The system is operating continuously during the winter months, posting

weather and traction advisories for use of chains on tires. In the summer months, HAR is used on an incident basis, and provides information on construction, delays, lane and road closures, are usually broadcast. WSDOT also turns on flashing beacon on the advisory signs for critical messages. Operators located in the TMC are responsible for controlling the traffic management equipment and recording/updating the HAR messages regularly.

Wyoming (16)

In the past 4 years, Districts I and III of the WyDOT have used HAR systems for road reports, black ice advisories, construction and maintenance activities. These Districts are primarily rural areas and the messages are broadcast from the radio dispatch office. The systems operate on frequencies 1610 kHz, and 1690 kHz. Flashing beacons are activated on static signs for road closures. Messages are broadcast continuously all year through cellular and hard-wire communications. District I initially communicated with the HAR system through cell phone however, during major accidents, cell phone communications became inundated with multiple users resulting in a system failure. Communications have since been electronically hard-wired.

Problems Identified by State Agencies

Nearly all the agencies interviewed addressed various problems associated with their respective HAR systems. The main problem cited by most agencies is maintaining up-to-date information for the driving public. The resources available for sustaining these messages are limited and other less resource-intensive technologies are used. Other problems identified deal with transmission interference due to topography, geography, and neighboring frequencies.

MESSAGE DEVELOPMENT

To be effective, the HAR messages must be designed and broadcast so that they provide drivers with correct and proper information from which appropriate driving and routing decisions can be made. Well-designed messages are essential for effective HAR systems (17). *The Manual On Real-Time Motorist Information Displays* provides suggested approaches to message development (18).

Message Format

HAR messages should be held to the minimum number of words necessary to communicate essential information. There is a significant reduction in performance if drivers hear the message only once. The language style should be concise. This is particularly important for diversion type messages especially where as many as 10 or more pieces of information must be recalled by drivers (2,18).

The format of an audio message can vary. However, there are several general principles for organizing audio messages for incident management and point diversion (18).

- The first statement in an audio message should be an attention statement alerting a facility user group or a particular destination group to attend to the message.
- The second message statement should give the problem (accident, construction, roadwork, etc.) and, in longer messages, the location of the problem followed by an effect on traffic (congestion, delay, lane closure).
- The final message should be an action message statement advising drivers what they should do about the problem. Action message statements vary from simple to complex. A simple message statement, for example, may tell drivers to exit and use the service road, or exit and follow the marked route

(marked with trailblazers.) A complex message statement describes the route that should be followed.

- When the initial attention statement addresses the facility user group and the action message statement applies only to a select destination group, and additional attention statement addressing the destination group must be included prior to the action message statement.

Table 3 illustrates three typical messages.

Table 3. Message Statement, and Statement Identifier Units (18)

Message Statement	Statement Identifier Units
ATTENTION NORTHBOUND CENTRAL FREEWAY TRAFFIC THERE IS AN ACCIDENT AT ROWLAND CONGESTION IS HEAVY YOU ARE ADVISED TO USE THE SERVICE ROAD EXIT AT MONROE AND REENTER NORTH OF CARTER CREEK	Attention Problem Effect Action
ATTENTION KYLE STADIUM TRAFFIC TO AVOID A MAJOR DELAY USE OXFORD AVENUE TO KYLE STADIUM	Attention Effect Action
ATTENTION NOTHBOUND CENTRAL FREEWAY TRAFFIC THERE IS AN ACCIDENT AT ROWLAND CONGESTION IS HEAVY DOWNTOWN TRAFFIC IS ADVISED TO USE CARSON AVENUE	Attention Problem Effect Attention Action

Message Repetition

The motorist should be able to hear the entire message twice while within the effective transmission range. Studies have shown that, although drivers encounter difficulties in repeating the entire audio message, they perform much better when following a route given in an audio message. The better performance is attributed to the drivers' need to only recognize street name signs at intersections rather than to recall them (18).

The suggested approach is to repeat the entire message when it is short. For long messages involving detailed diversions instructions, it is acceptable and more practical to repeat only the action message statement (18). An example of repetition of the action message statement is in Table 4.

Use of Trailblazers

For complex diversion routes requiring more than an 8-unit action message statements (Diversion Message), trailblazers must be used along the diversion route. There are three basic audio approaches when trailblazers are used along the diversion route (18):

Table 4. Repetition of the Action Message Statement (18)

Message Statement	Statement Identifier Units
ATTENTION SOUTHBOUND INTERSTATE 75 TRAFFIC THERE IS AN ACCIDENT AT POULSON CONGESTION IS HEAVY TO BYPASS THE ACCIDENT, YOU ARE ADVISED TO EXIT AT KINGMAN ROAD TURN RIGHT ON KINGMAN LEFT ON ANDERSON AND LEFT ON RILEY BACK TO INTERSTATE 75	Attention Problem Effect Action Action Action Action Action
I REPEAT: TO BYPASS THE ACCIDENT, YOU ARE ADVISED TO EXIT AT KINGMAN ROAD TURN RIGHT ON KINGMAN LEFT ON ANDERSON AND LEFT ON RILEY BACK TO INTERSTATE 75	 Action Action Action Action Action

- Give a detailed description of the diversion route and tell drivers to follow the marked route,
- Do not give a detailed description of the diversion route, but tell drivers where to exit and to follow the marked route; and
- Do not give a detailed description of the diversion route, but tell drivers which route to use (e.g., use Fitzhugh Avenue).

TEXT-TO-SPEECH TECHNOLOGIES AND PROPOSED INTEGRATION OF HAR

Text-To-Speech

TTS is the process of converting text – usually in the form of American Standard Code for Information Interchange (ASCII) files – to speech output. It is used in applications where it is inconvenient or impossible to record a human speaker. For example, TTS can be used to “read” a fax or E-mail message to a caller or to retrieve and “read” information from a large, frequently changing database. Although TTS has been commercially available for over 12 years, few developers could afford to include it in their applications because these tasks once required expensive, specialized hardware that drove up the cost of applications and discouraged wide use of the technology. Today, the cost of computer-based telephony hardware has declined significantly and extensive Central Processing Unit (CPU) power is readily available, allowing applications to be implemented in a more cost-effective fashion. In short, the previous barriers to the deployment of TTS technologies have disappeared (19).

The operating system for the TransGuide TMC is an integration of commercial-off-the shelf products and custom code. Solaris™ is a Unix based operating system employed at TranGuide. Two TTS technologies have been found to support Solaris platform utilizing C++. AT&T® and Fonix® both manufacture TTS that can be integrated into the TransGuide operating system.

Preliminary testing was conducted on the TTS demos provided on the websites of both manufactures' to determine the quality of an example HAR message. The messages designed for case 1, 2, and 3 (in the message design section) were used to test for quality and delivery of a potential HAR message being broadcast. The messages were delivered in both a male and female synthesized voice. The quality of the voices and spacing of the statements were acceptable however, the test demonstrated that the number "410" is synthesized as four-hundred-and-ten, but "4,10" or "4" (space) "10" is synthesized as four-ten. Also, the names of streets have the potential to be mispronounced (e.g., La Cantera in design case 3).

Integration

Having the HAR messages linked to the DMS scenario database will allow for continuity between the messages displayed on a DMS and a message broadcast on HAR. Messages that are displayed on a DMS are derived from the TransGuide scenario database from which there is up to 40,000 preplanned scenarios. Normally, these scenarios are based on alarm location and information that is provided by the operator (20). Table 5 shows the scenario classification and meaning.

An HAR scenario database should be created similar to the DMS scenario database. For all classes of scenarios listed in Table 5, there should be corresponding HAR messages.

TTS software should utilize the proposed HAR scenario database allowing for system integration. Any incident initiating alarms on DMS_A or DMS_B as shown in Figure 5, should automatically activate the HAR messaging system in the form of a text box comparable to that of the DMS text box. Defined as "HAR MESSAGE," the text box should permit for more detailed information as opposed to information displayed on the "DMS MESSAGE" text box.

Once the HAR message has been finalized and transmitted by the Assignment Plan Manager, similar to the DMS process, the flashing beacons on the advisory sign(s) should be activated simultaneously. When the incident has cleared the operator cancels the DMS scenario and runs an appropriate or default scenario. When this occurs, the flashing beacons should be deactivated automatically and the HAR messages should parallel the message being displayed on the DMS.

Table 5. Scenario Classification and Meaning (21)

Scenario Classification	Scenario Meaning
Major Accident	An accident that will cause 15 minutes of delay or longer
Minor Accident	An accident that will cause less than 15 minutes of delay
Congestion	Occurs as a result of an incident (e.g., accident, congestion, debris, construction/maintenance, or adverse weather conditions) OR A stalled vehicle on either the main lanes or shoulder
Debris	Debris is on the roadway and will interfere with the roadway
Construction/Maintenance	Includes scheduled lane closures as well as inform the motorist of maintenance on shoulders that may not have lane closures
Weather Conditions	These scenarios shall include water on roadway as well as ice
Travel Times	Used from 6 AM to 10 PM daily when traffic is free-flowing

In the case where there are no incidents, default messages can be created and broadcast on HAR. These messages can include information such as travel times, general safety, public transit, or perhaps the

message, "NO MESSAGE AT THIS TIME." With the availability of a weather radio, TransGuide will have the potential to broadcast weather information.

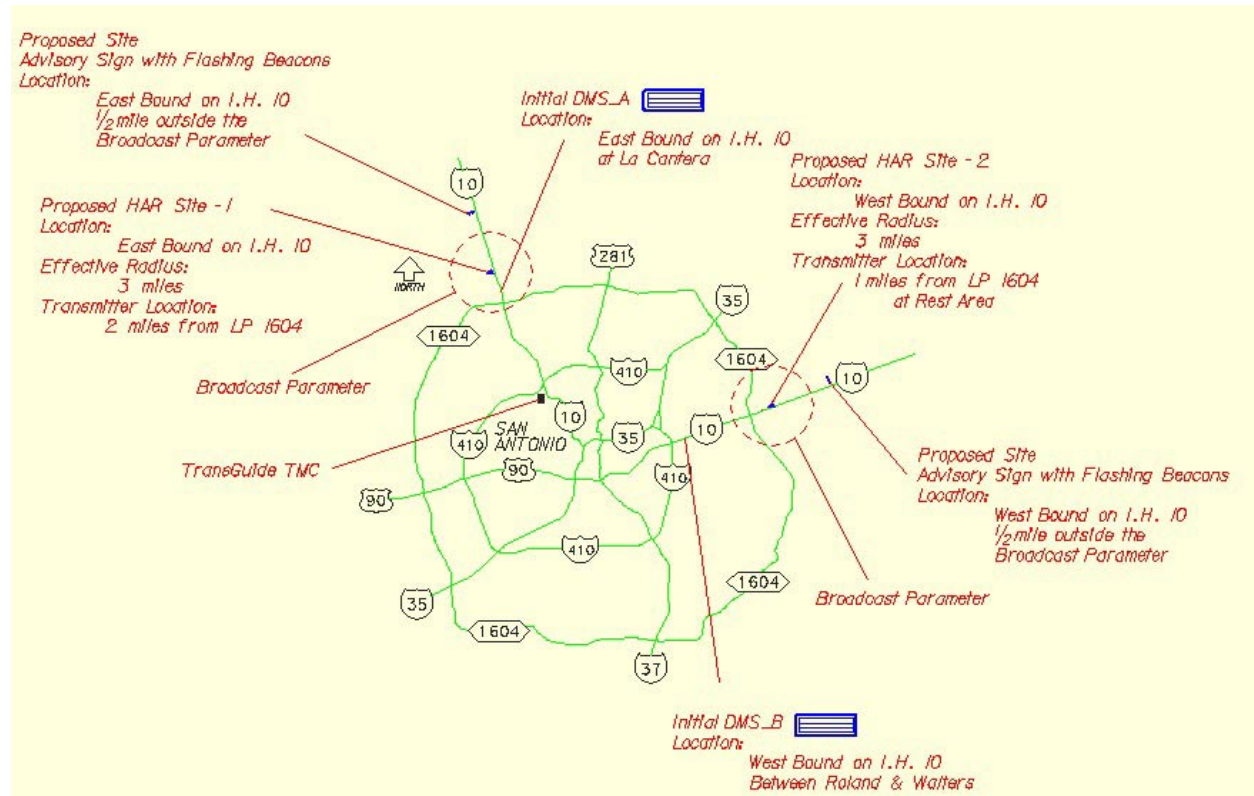


Figure 5. Proposed HAR Locations

Diagnostic Features

Through developed software the HAR system should be polled for proper function, communication, and confirmation of message. Prior to dispatching an HAR message, a playback feature should be created to ensure the quality of the message. In the event there is a malfunction in any of the HAR operations, an alarm could then be generated and sent to the Assignment Plan Manager, where the error can be evaluated and corrected. These diagnostic features should be self-generating thereby reducing human intervention.

Proposed HAR System Architecture

The proposed architecture of the HAR system is presented in Figure 6.

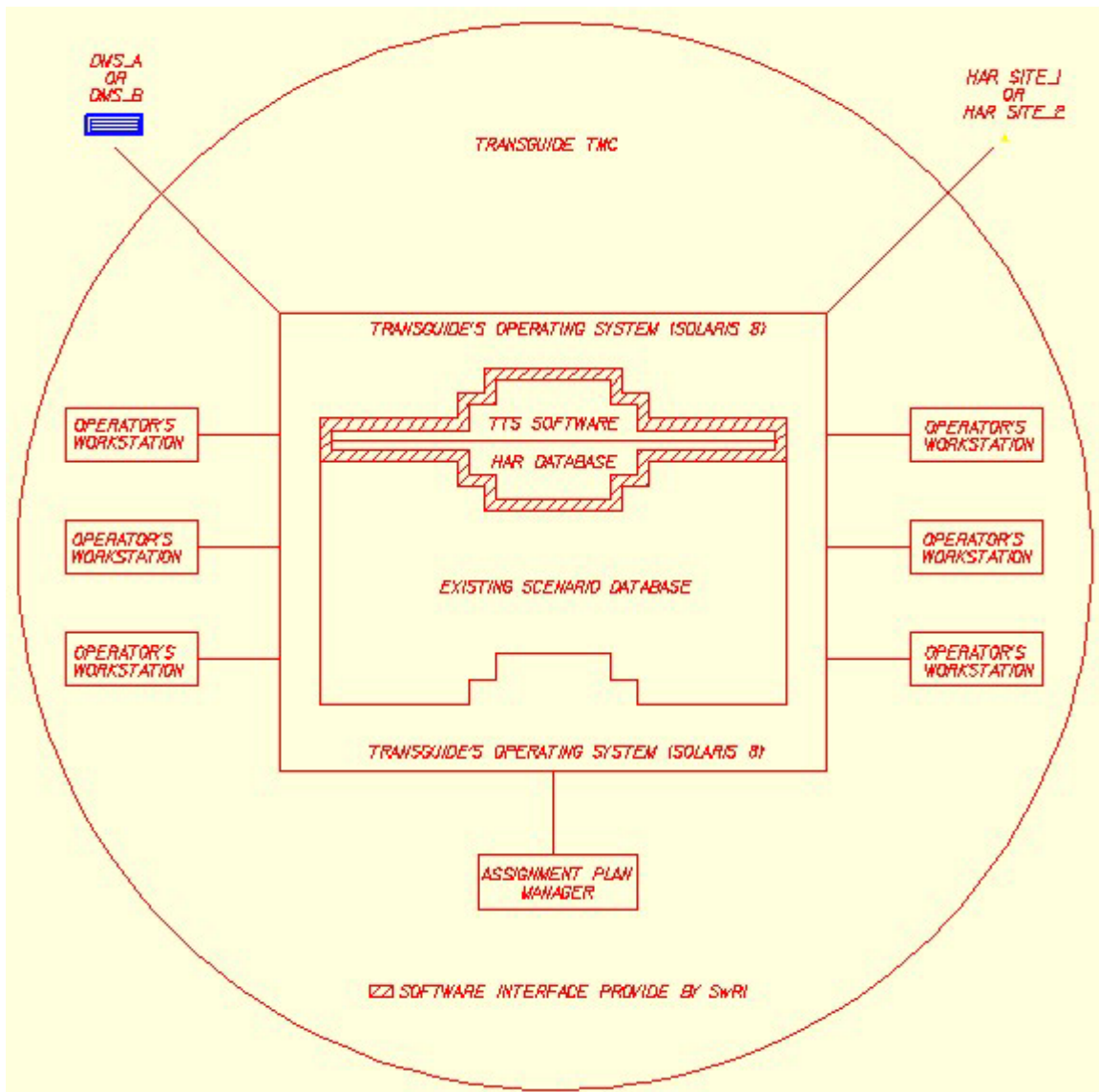


Figure 6. Proposed HAR System Architecture

To begin, vehicle detection devices are installed on major highways and send important information to the TransGuide Operating System. When vehicles decelerate to a speed below 20 mph a major alarm is generated at the operator's workstation, where the operator can then verify the alarm with a CCTV. Upon verification, the operator will select the type of incident and the number of lanes closed. When the operator indicates that the selection criteria have been completed, the TransGuide Operating System selects a specific scenario that matches the set of selection criteria determined by the location of the alarm and operator's selections (20). At this time, separate DMS and HAR message text boxes should be displayed on the operator's screen allowing for editing if needed. The DMS message is processed from the scenario database to the TransGuide Operating System. While the HAR message should be processed from the HAR scenario database through the TTS software and then to the TransGuide Operating System. Once editing has been completed, both messages should be sent to the Assignment Plan Manager for approval. After approval both messages are sent for display and broadcast.

Message Design

The design messages will be based on two types of incidents: Major Accidents and Travel Time. Figure 7 illustrates the location of design cases one and two.

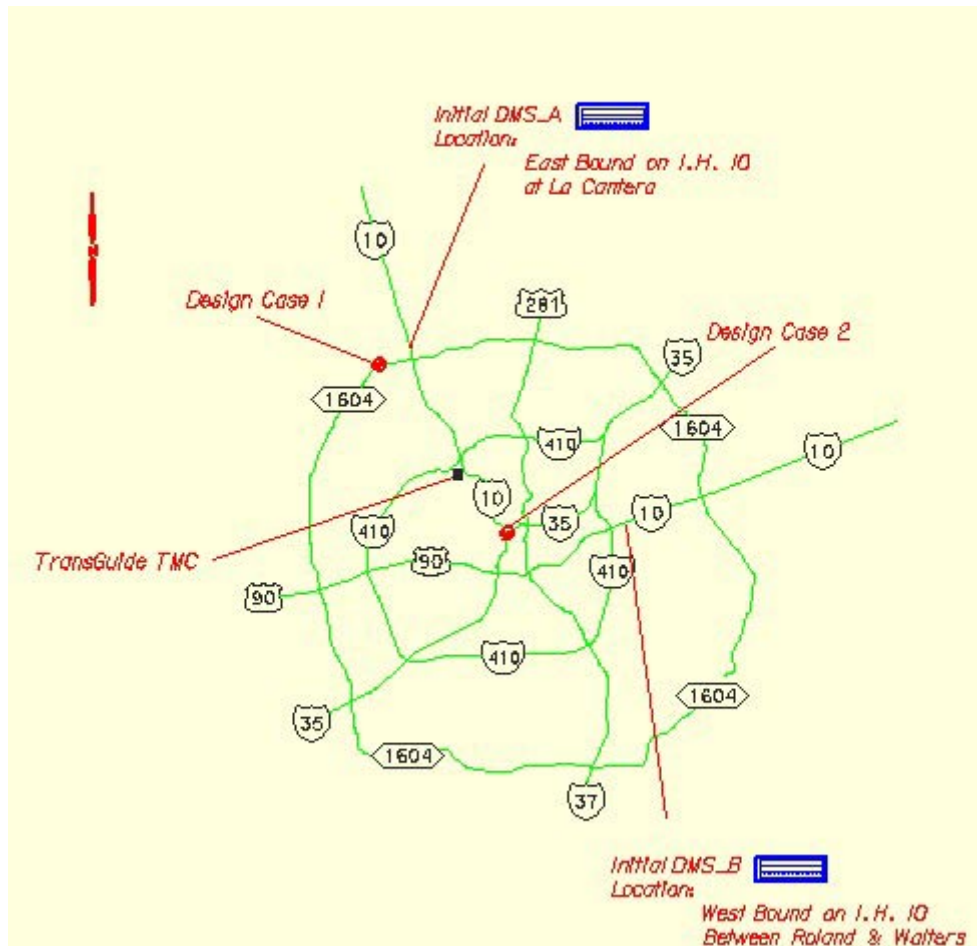


Figure 7. Incident Locations for Design Case 1 and 2

Design Case 1

Table 6 summarizes the situation and messages that would be displayed and broadcast in the event there was a major accident. Figure 8 details the location of the incident and the recommended diversion route.

Design Case 2

In many cases, when an accident occurs, there may be many alternatives in route diversion. Rather than divert motorist to a specific route when multiple diversion routes exist, it is the policy at TransGuide to give the motorist enough information so that a proficient decision can be made. Table 7 demonstrates this particular situation and also shows the corresponding DMS and HAR message. Figure 9 details the location of the incident.

Table 6. Design Case 1

Situation	DMS_A Message
Left Lane Closed MAJOR ACCIDENT on LP 1604 West at John Peace Blvd. Demand Greater Than Capacity Audience: Motorist Traveling on I.H. 10 East to LP 1604 West There is an exit between driver and closed lane	MAJOR ACCIDENT ON LP 1604 WEST USE CAUTION
HAR Message	
ATTENTION EASTBOUND I.H. 10 TRAFFIC THERE IS A MAJOR ACCIDENT ON LP 1604 WEST AT JOHN PEACE BLVD. CONGESTION IS HEAVY TO BYPASS THE ACCIDENT USE THE FRONTAGE ROAD EXIT AND REENTER WEST OF JOHN PEACE BLVD I REPEAT: TO BYPASS THE ACCIDENT USE THE FRONTAGE ROAD EXIT AND REENTER WEST OF JOHN PEACE BLVD	

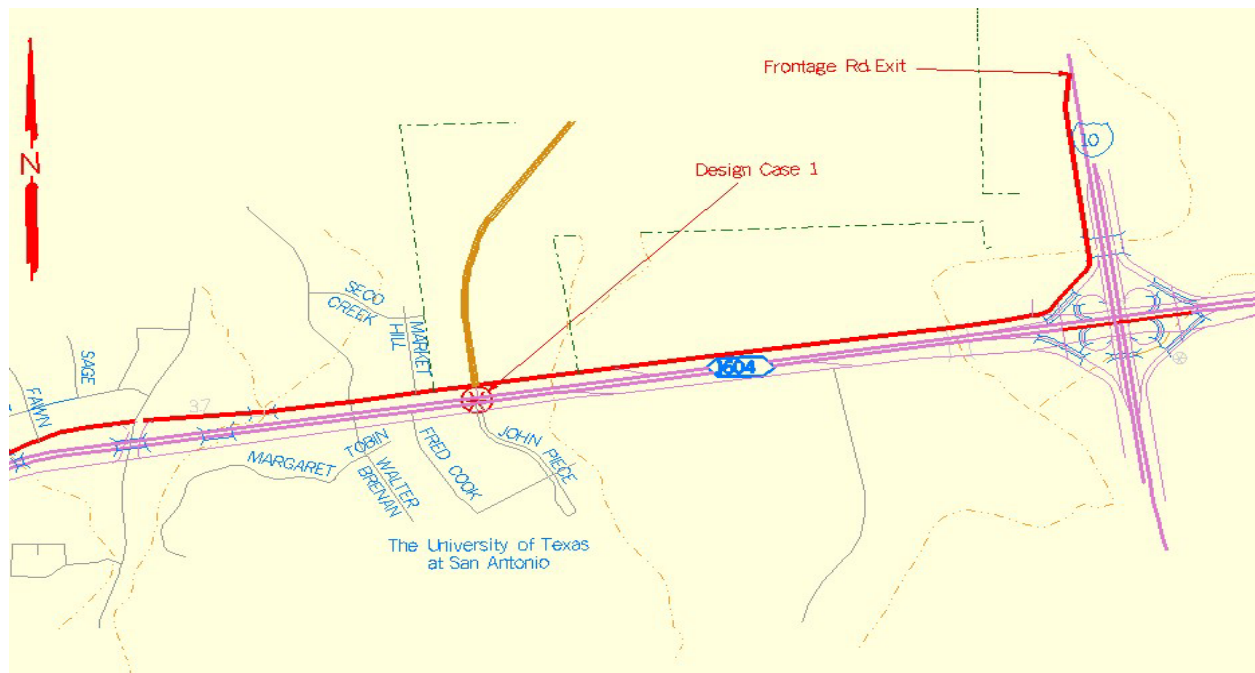


Figure 8. Recommended Diversion Route

Table 8. Design Case 3

DMS_A Message
TRAVEL TIME TO IH10/LP410 INTCHG 7-9 MINS
HAR Message
ATTENTION EASTBOUND I.H. 10 TRAFFIC TRAVEL TIME FROM LA CANTERA TO I.H.10/LP 410 INTERCHANGE IS SEVEN TO NINE MINUTES I REPEAT: TRAVEL TIME FROM LA CANTERA TO I.H.10/LP 410 INTERCHANGE IS SEVEN TO NINE MINUTES

RECOMMENDATIONS

The following recommendations are offered to the TransGuide TMC for implementation and effective operations of the HAR system.

1. TransGuide should formally adopt the *Manual On Real-Time Motorist Information Displays* for guidance on developing the messages proposed for the HAR database.
2. Investigate solutions for correcting the pronunciation of street names and numbers demonstrated by the use of TTS software.
3. Since Interstate Loop 410 is designated as a Hazardous Cargo Route, messages should be designed for those vehicles when considering route diversion.
4. Have SwRI (Software Integrator and Maintainer) develop the proposed HAR database, software interface and diagnostic protocols for the HAR system.
5. Integrate the HAR software into the TransGuide Operating System.
6. All HAR transmitters, permanent or portable, should be operated from the TransGuide TMC.
7. Consider placing transmitter(s) on I.H. 10 East and West as shown on Figure 5.
8. Consider installing weather radio for weather information.
9. Purchase the HAR advisory signs with flashing beacons.
10. Make the advisory signs highly visible.
11. Consider placing advisory sign ½ mile from broadcast zone.
12. Once a decision has been made on the location of the transmitter(s) and prior to deployment, a public relations campaign should be undertaken to educate citizens about what HAR is, and what types of information they can expect to receive.
13. Have the contractor provide all services to prepare a FCC license application package, and also provide a technical services basic site preparation package including a site survey of each HAR site.

CONCLUSION

HAR allows agencies the ability to provide a variety of detailed information from current traffic conditions to general safety. The success of the system relies heavily on the timely and up to date messages being broadcast. Motorists look to these systems to furnish them with reliable and accurate information. Precautions must be taken to insure the credibility and success of an HAR system. Although this success is largely dependent on personnel, it is conceivable that the TransGuide software

platform, which supports open architecture, will allow for an effective integration of an HAR system. Through TTS, an HAR scenario database, and diagnostic features insuring quality control, it is likely the HAR system proposed at TransGuide will have minimal human intervention.

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The author would like to thank each of the Mentors for their guidance and insight. The author expresses sincere thanks to James L. Wright and Pat Irwin for their contributions, support, and encouragement throughout the duration of this program. A very special thanks is extended to Dr. Dudek for organizing this program and allowing the opportunity to interact with distinguished professionals in the ITS industry.

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- Mr. Victor Gil, Texas Department of Transportation
- Mr. Derrick Burke, Texas Department of Transportation
- Mr. Michael Gousse, Washington Department of Transportation
- Mr. Tim McGary, Wyoming Department of Transportation
- Mr. Ted Wells, Wyoming Department of Transportation

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APPENDIX A: SAMPLE INTERVIEW QUESTIONS

1. How long has your HAR system been in place?
2. Are the HAR system(s) deployed mostly in Urban or Rural Areas?
3. What type of information is broadcast in Urban areas vs. Rural areas? (Compare and Contrast)
4. What is the broadcast area? (Distance/Radius)
- 5a. For what specific applications do you use HAR? (work zones, accidents, tourism, etc.)
- 5b. Is the HAR system continuously broadcasting information?
6. Is the HAR system(s) operated from a traffic management/operations center?
 - Benefits?
 - Limitations?
- 7a. What type(s) of commercial HAR equipment do you deploy in your area?
 - Name?
 - Model?
 - Capability?
- 7b. Has the HAR system experienced any significant maintenance issues? (Vandalism, power supply)

8. Do the messages have to be pre-recorded (canned) or are they text to speech translations? If they are direct text-to-speech, what technologies do you employ?
9. What is the quality of the broadcasts?
10. What type of equipment do you use to attract the public's attention for the HAR?
11. Do you use portable HAR systems, and if so when?
12. What were the procedures for acquiring a FCC license?
13. What frequencies do you broadcast over?
14. Is your HAR system effective?
15. How do you measure HAR's effectiveness?
16. Is the HAR system personnel-intensive?

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IMPLEMENTATION AND OPERATIONAL GUIDELINES ON COORDINATED RAMP METERING SYSTEMS

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SUMMARY

Ramp metering, as a major component of Advanced Transportation Management Systems (ATMSs) has been used in over 25 metropolitan areas in the United States. This paper is prepared to document the issues related to deployment of system-wide coordinated ramp-metering systems. Guidelines are developed regarding implementation and operations of coordinated ramp-metering systems based on comprehensive literature review and agency surveys.

A coordinated freeway ramp-metering system is used to control a series of entrance ramps where the interdependency of entrance ramp operations is taken into consideration. The overall objective of coordinated ramp-metering system is to improve efficiency and safety of freeway systems. A summary is provided regarding the current status of ramp metering, especially coordinated ramp-metering system applications in the United States. The issues related to the various aspects of coordinated ramp-metering systems and the procedures for implementing such systems are addressed. Guidelines are provided to achieve successful system implementation and operations. The features of the representative ramp-metering algorithms are described. These algorithms represent the most advanced algorithms that have been successfully implemented and tested in the field. Guidelines are also developed to address the system performance evaluation process. Performance measures are recommended for conducting system evaluations. Results of various performance measures from previous studies are provided based on different types of ramp metering systems.

This document contains information about the state-of-art technologies and developments in the area of coordinated ramp-metering systems in the United States. The guidelines developed through this research can assist transportation agencies in dealing with various issues involved in the process of implementing coordinated freeway ramp- metering systems.

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INTRODUCTION

Ramp metering has been used as one of the major freeway management techniques (*1*). It offers several operational features for improving freeway traffic flow, safety, and air quality by regulating the flows onto the freeway system. Appropriate application of various ramp-metering strategies can be effective in maximizing system throughput and minimizing delay under both recurrent congestion and non-recurrent congestion.

One of the ramp-metering strategies is to operate all the ramp-metering signals in an integrated control system. Integrated ramp-metering systems can be viewed at different levels and aspects. At a local level, an integrated system may indicate the integration between an individual ramp and the adjacent surface street signal, such as at a diamond interchange (*2,3*). At a system-wide level, an integrated ramp-metering system may indicate coordination among all the ramp meters (namely coordinated freeway ramp-metering system) to improve freeway system operations (*4,5,6*), or the integration of the freeway ramp-metering system with surface street arterial systems (*7,8,9,10*). Currently, only coordinated freeway ramp-metering systems have been successfully implemented in the United States. Although integrated freeway/surface street systems have been attempted in the field, the true system integration has not yet been achieved, mainly due to technological barriers such as communication between the freeway system and the surface street system (*7,8,10*). With various ITS deployments throughout the major metropolitan areas in the United States, there has been a growing interest in implementing coordinated freeway ramp-metering systems. There are several questions that transportation agencies would like to know about coordinated ramp-metering systems. For example, what is the benefit/cost ratio for implementing coordinated ramp-metering systems compared to fixed or traffic-responsive ramp-metering systems? What is the expected range of various performance measures for different types of ramp-metering systems? What is the best control algorithm to be implemented? These are the questions that this paper is intended to address.

Problem Statement

Although ramp metering has been around for more than 40 years, the implementation and operation of coordinated ramp-metering systems are still limited. The design, implementation and operation of such systems involve many issues and challenges. Currently, there are no specific guidelines to address the issues associated with coordinated ramp-metering systems. Development of a set of guidelines based on past experience and research would assist transportation agencies to achieve a successful system implementation process.

Scope

The scope of this paper is limited to address coordinated freeway ramp-metering systems. The control systems and operating algorithms documented in this paper are primarily those that have already being implemented in the United States. The issues addressed include system planning and design, ramp metering algorithms, system performance measures and evaluation process, and benefit/cost ratio analysis. Theoretically and mathematically oriented research products are beyond the scope of this paper.

Objectives

The primary goal of this research is to document the various aspects of coordinated ramp-metering systems, and to develop guidelines to assist transportation agencies toward successful design, implementation and operation of coordinated ramp-metering systems. The outcome of the project will enhance the knowledge base on coordinated ramp-metering systems. The following major objectives were identified:

- Address the various issues associated with system design, implementation, operation, and evaluation.
- Develop general guidelines for system deployment process.

- Investigate coordinated ramp-metering algorithms, and establish guidelines for selecting an appropriate ramp-metering algorithm.
- Recommend a set of system performance measures and develop guidelines for a system evaluation process.

RAMP METERING AND CLASSIFICATIONS

Ramp Metering Components

Figure 1 is a sketch of a typical ramp-metering design and its various components. A ramp-metering system may include several detectors. These detectors are located on both the mainline and the ramp, which are critical elements to achieve different operating strategies. Depending on the control strategy, different detector information may be used. For example, no detector information is necessary to operate a fixed time metering plan. To operate with traffic-responsive metering strategy, the mainline detectors are necessary to detect current freeway conditions, but the location of the detectors and the operating parameters may vary depending on the control algorithm. Some algorithms may only use one set of detectors, either upstream or downstream, while some algorithms may use both the upstream and downstream detectors. Some algorithms use volume, speed, density or occupancy. A detailed discussion on the traffic responsive algorithms will be given in a later section. Regardless of the types of ramp-metering operations, the metering rate is governed by the minimum and maximum metering rates, which are directly related to the timing parameters. Table 1 is a summary of the typical timing parameters used by different states based on a recent survey.

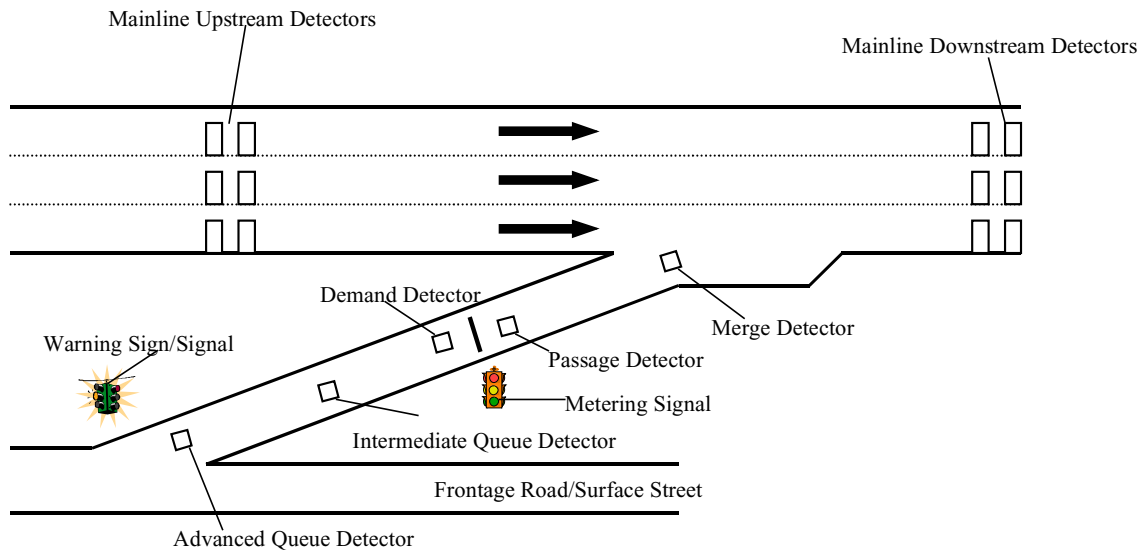


Figure 1. Ramp Metering Components

Table 1. Timing Parameters for Ramp Metering

State	Timing Parameters, sec		
	Green	Yellow	Red
Arizona	1.5	NA	1.5~10.0
California	2.0	2.0 ¹	2.0~15.0
Colorado	2.0~2.5	NA	2.0~13.0
Georgia	1.5	NA	2.5~8.0
Illinois	1.0	NA	3.0~12.0
Michigan	1.5	NA	2.5
Minnesota	1.3	0.7	0.1~13.0
Oregon	2.0	NA	0.4~12.0
Texas	1.0 1.0~5.0	1.0 1.7	2.0~5.0 ² 2.0~4.0 ³
Wisconsin	2.0~2.5	NA	2.5~10.0 ⁴ 1.8~8.0 ⁵
Utah	2.0	NA	2.0

Notes: 1. Used when cycle is greater than 6 seconds or 2 car per green

2. For fixed time ramp meter

3. For traffic-responsive ramp meter

4. For single lane ramp meter

5. For multi-lane ramp meter

As shown in Table 1, green and red intervals are used for all ramp-metering locations. However, the yellow interval is optional. The green interval ranges between 1.0 to 2.0 seconds, and the yellow interval ranges between 0.7 to 1.0 seconds. The green and yellow intervals are usually fixed during metering operations. It is the variation of the red interval that determines the metering rate. The red interval is typically between 2.0 to 15.0 seconds. A typical metering cycle (a combination of green, yellow, and red intervals) is between 4.0 and 15.0 seconds, which translate into a metering rate between 900 vph and 240 vph for a single-lane ramp metering. Any timing cycle shorter than 4.0 seconds may not achieve the objective that each vehicle must stop at the metering signal. Any timing cycle longer than 15.0 seconds will likely result in driver frustration and high violation rate. As a result, a single-lane ramp metering is recommended if the ramp demand is between 240 vph and 900 vph. A multi-lane ramp meter can achieve maximum metering rates between 1600 vph and 1800 vph, and thus recommended if the ramp demand exceeds 900 vph.

Ramp Metering Classifications

Ramp-metering systems can be classified from different perspectives in terms of design and operations. Figure 2 illustrates the types of ramp-metering systems and their classifications.

As can be seen from Figure 2, ramp-metering systems can be classified based on operations level, geometry, location, and operations rule. Based on the complexity of operations level, a ramp metering system can be classified into four types: local fixed time, local traffic responsive, coordinated freeway ramp metering, and integrated freeway/surface street system. Local fixed time (or pre-timed) metering is

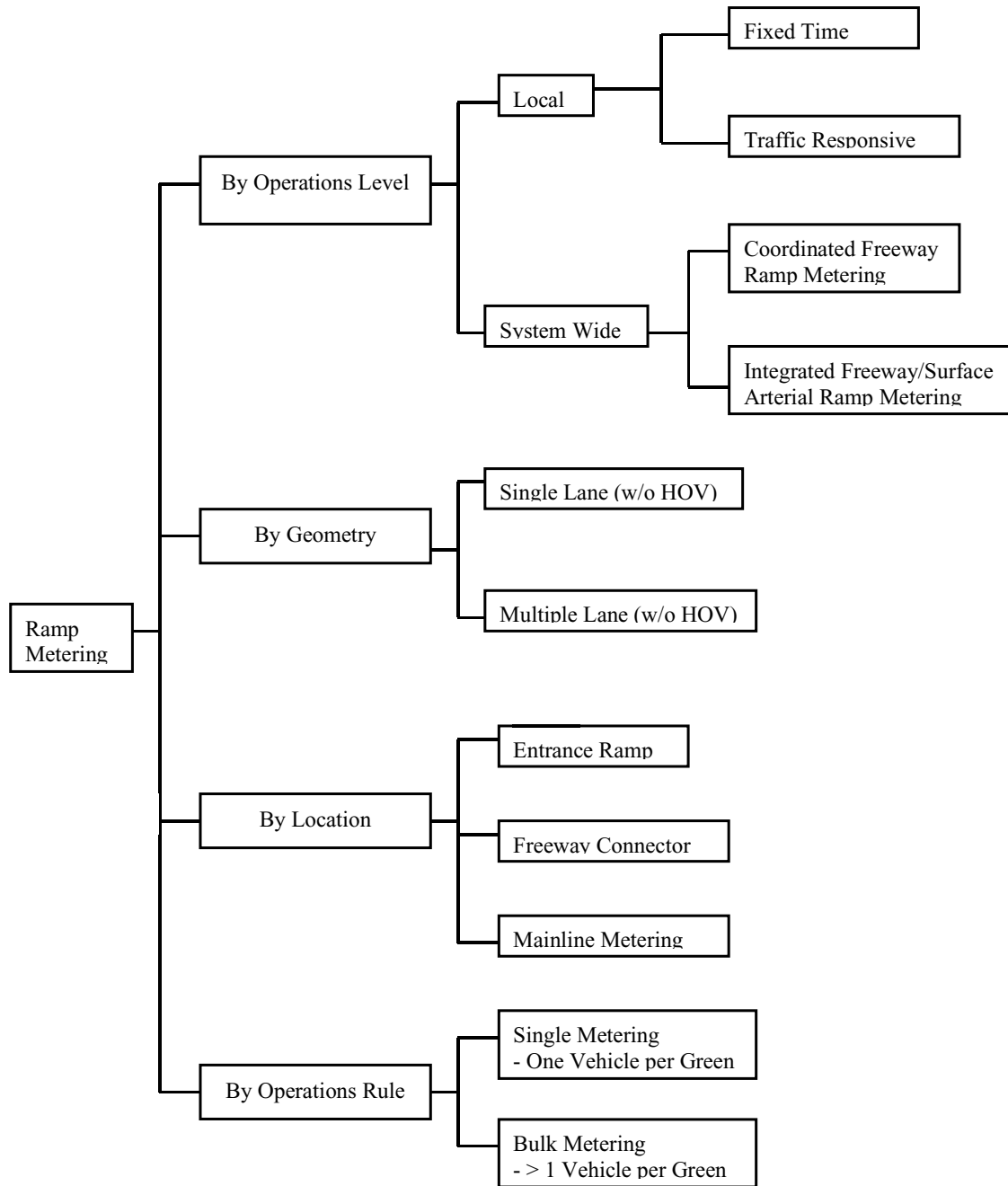


Figure 2. Ramp Metering Classifications

the simplest form. Both the metering rate and the metering time period are pre-defined based on historical data, such as mainline volumes and existing ramp volumes. Fixed time metering cannot respond to traffic condition changes; therefore, it only applies where the traffic flow patterns are easily

predictable, or it mainly serves as a means to break up platoons. Local traffic-responsive ramp metering establishes metering rate based on information from various detectors on both the mainline and the ramp, and the objective is to control the ramp flow to prevent freeway congestion in the vicinity of the ramp location.

More sophisticated systems are system-wide ramp-metering systems, which include coordinated freeway ramp-metering systems and integrated freeway/surface street systems. A coordinated freeway ramp-metering system controls a series of entrance ramps where the interdependency of entrance ramp operations is taken into account. The basic principle of coordinated freeway ramp-metering systems is to control the total traffic volumes to not exceed the system's bottleneck capacity. Ramp metering rates at each individual ramp are determined from a system point of view. Coordinated ramp-metering systems have been implemented in several metropolitan areas, and are the focus of this paper. Another type of system-wide metering system is called the integrated freeway/surface street system, where the operations of the freeway system and the surface street system are considered as an integral component. For example, surface street signal systems should be able to react to traffic diversion resulted from freeway ramp metering, and freeway ramp metering should minimize the adverse impact on the surface street system (9). While the concept of such a system is good, actual implementation and operations have been experiencing significant challenges, mainly due to technology barriers in communications between surface street system and freeway system, which are maintained by different jurisdictions (7,8,10). The expected integrated operations have not been able to achieve the desired performance.

Based on ramp geometry design, there are single-lane ramp metering and multiple-lane ramp metering. Both types can accommodate a Highway Occupancy Vehicle (HOV) by-pass lane. Multiple-lane ramp metering design has several operational advantages over the single-lane metering design. Most evident advantages include higher metering rates and increased queue storage. Wherever geometric conditions permit, a multiple-lane ramp metering is always recommended (11).

Ramp metering is typically located on freeway entrance ramps. However, simply metering the entrance ramps may not be enough to prevent bottleneck congestion. Two other types of metering include freeway connector metering (freeway-to-freeway) and freeway mainline metering, as being used in the states of California, Minnesota, Washington, and Virginia.

Most ramp-metering operations adopt the rule of one vehicle entry per green with a green interval typically ranging between 1.0 to 2.0 seconds. Bulk metering (also named platoon metering) allows more than one vehicle entry per green for the purpose of increasing the metering rate for a single-lane metering design. However, a study conducted at Texas Transportation Institute (TTI) (12) showed that bulk metering can only increase the metering rate by about 30 percent due to the increase in the required metering cycle. Bulk metering is currently used in some states (e.g., Texas and California) where the ramp demand exceeds the single-lane metering capacity. For example, bulk metering is used in Texas where the ramp demand exceeds 900 vph at single-lane ramp metering locations.

STATUS OF RAMP METERING IN THE U.S.

Since the first ramp metering applications in the early 1960's in the Chicago, Detroit, and Los Angeles areas, there has been a significant growth in the number of ramp metering locations. Based on review of previous literatures (13,14) and recent agency survey (*Appendix A*), there are more than 2000 ramp meters currently operating at more than 25 metropolitan areas in the United States. Most growth occurred in the areas where ramp metering has been viewed as successful and with good public support. A good example of ramp-metering growth can be demonstrated by the states of Wisconsin, Washington, Arizona and Oregon. Between 1998 and 2002, the number of ramp meters increased by 160 percent, 130 percent, 88 percent and 83 percent for the above four states, respectively. Although ramp metering has shown

significant benefits in improved safety and freeway operations, some states still hesitate to implement ramp metering, primarily due to concerns of public resistance.

Figure 3 is a summary of the status of coordinated ramp-metering system implementations in the United States. Table 2 includes more detailed information regarding each ramp metering system, including the metering type and the algorithm used for coordinated ramp-metering operation.

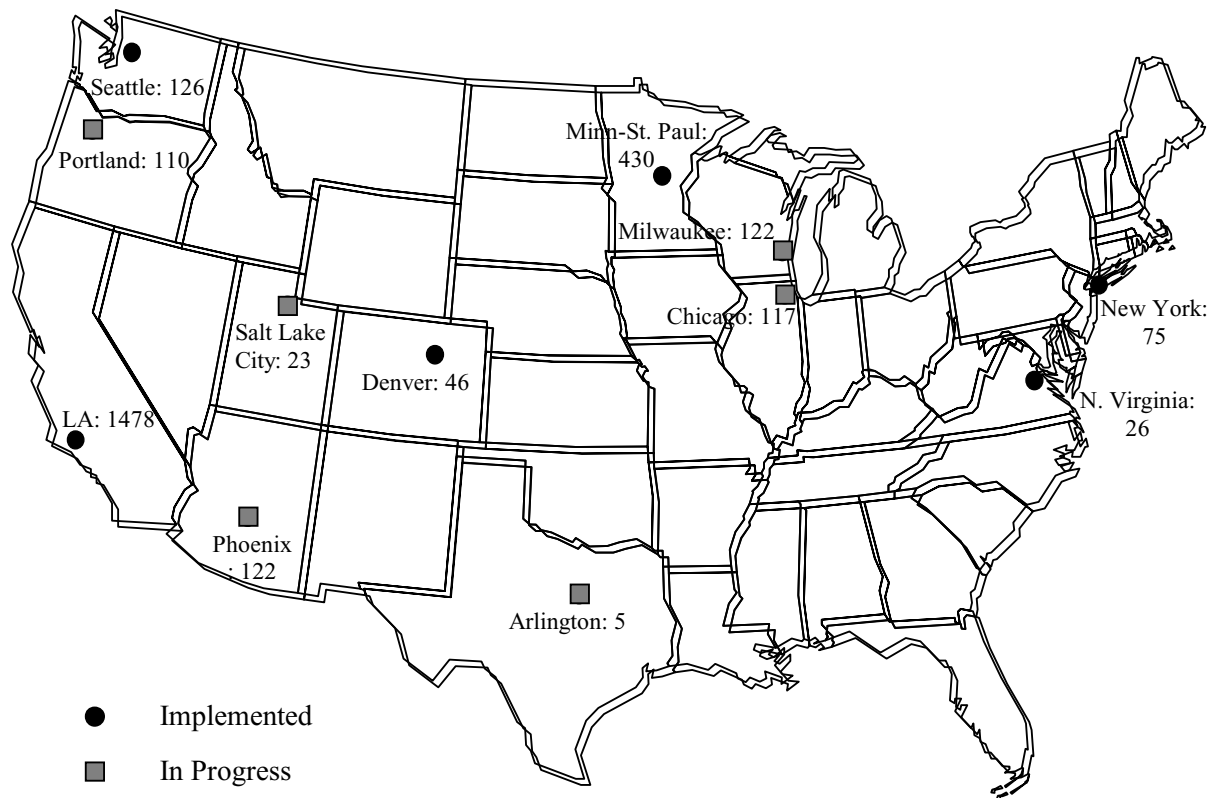


Figure 3. Coordinated Ramp Metering System Implementation

Currently, there are six metropolitan areas where coordinated freeway ramp-metering systems have been implemented. There are six metropolitan areas where the metering systems are being upgraded from either fixed time or traffic-responsive control to coordinated control. Due to the success of ramp metering and the advance in technologies, there is a trend to expand the existing ramp-metering system and to integrate the system with other Advanced Transportation Management System (ATMS) components. It is believed that ramp metering would achieve the greatest benefits when it is combined with full ATMS implementations, such as the Advanced Traveler Information Systems (ATIS), Incident Management Systems (IMS), and surface street systems (15). It is important to mention that integrated freeway/surface street systems have not yet been much a success. The State of Washington designed an integrated system but didn't get final approval for implementation (16). Both the States of California and Minnesota have implemented integrated systems, but were never fully functioning (8,10). One of the common problems is communication between the freeway management system and the surface street system, which are separately maintained by the state and the city.

Table 2. Summary of Ramp Metering Status

Metropolitan Area	Number of Ramp Meters				System Status and Coordination Algorithms
	F ¹	R	C	Total	
Arizona					
Phoenix	30	-	55	122 ²	In Progress: MILOS
California					
Fresno	-	38	-	38	
Los Angeles	-	-	838	838	SWARM
Orange County	-	-	288	288	SWARM
Sacramento	-	60	-	60	
San Bernardino	-	141	-	141	
San Diego	-	267 ³	-	267	
San Francisco	-	191	-	191	
San Luis Obispo	-	2	-	2	
Colorado					
Denver	-	2	44	46	HELPER
Georgia					
Atlanta	5 ⁴	-	-	5	
Illinois					
Chicago	-	-	117	117	In Progress: SWARM
Michigan					
Detroit	59 ³	-	-	59	
Minnesota					
Minn - St. Paul	-	-	430	430	ZONE
New York					
Long Island	-	-	75	75	Unknown
Oregon					
Portland	10	-	100	110	In Progress: SWARM
Ohio					
Cleveland	3	-	-	3	
Columbus	6	-	-	6	
Pennsylvania					
Philadelphia	16	-	-	16	
Texas					
Arlington	5 ⁴	-	-	5	In Progress: RAMBO II
Houston	70	58	-	128	
San Antonio	1	-	-	1	
Utah					
Salt Lake City	23	-	-	23	In Progress: Unknown
Virginia					
Arlington	-	-	26	26	SPERRY
Washington					
Seattle	-	-	126	126	BOTTLENECK; FUZZY
Tacoma	1	-	-	-	
Wisconsin					
Milwaukee	19	103	-	122	

Note: 1. F – Fixed; R – Local traffic-responsive; C – Coordinated

2. Phoenix currently has 122 metering locations with 85 are running.

3. Metering systems in San Diego and Detroit used to be coordinated, but were decentralized due to computer system update and re-construction

4. The ramp meters in Texas and Georgia were designed as traffic responsive, but are operating as fixed time

COORDINATED RAMP METERING SYSTEM DEPLOYMENT PROCESS

The deployment of coordinated ramp-metering systems is a complicated process. Figure 4 is a recommended procedure for the deployment process.

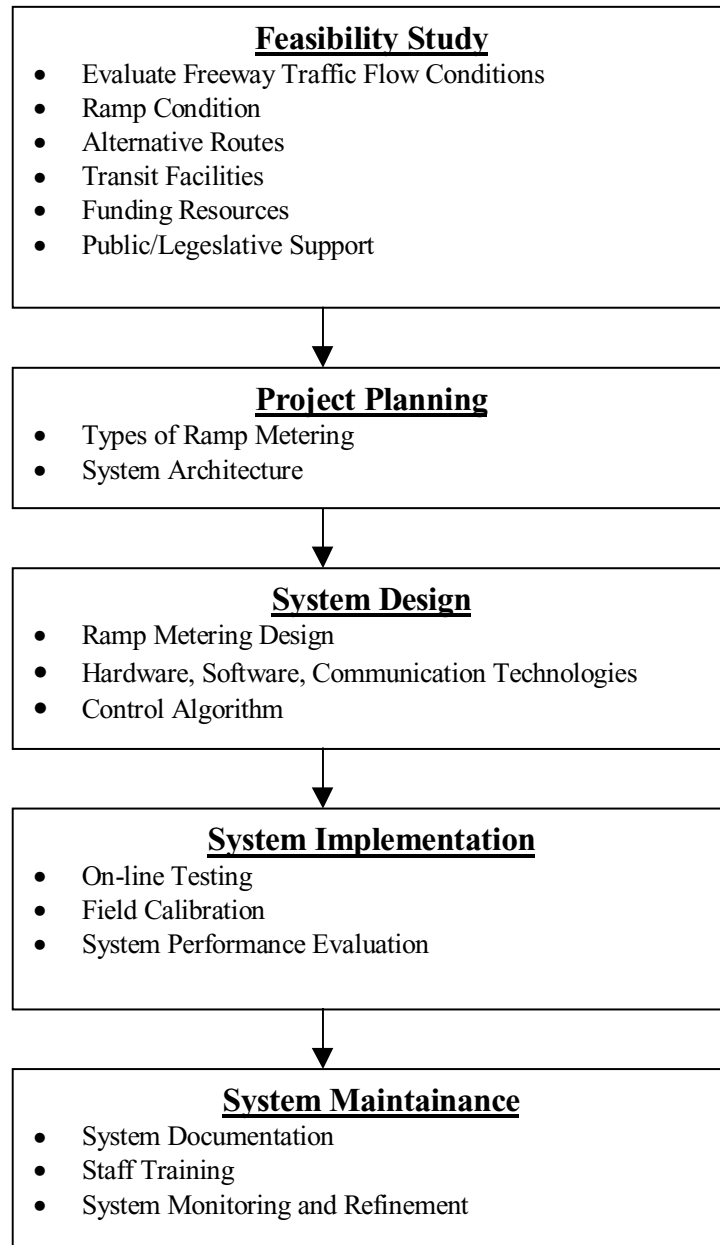


Figure 4. Coordinated Ramp Metering System Design and Implementation Process

Similar to other system deployment projects, a feasibility study must be conducted to investigate whether a ramp metering system can be physically designed and operational effective. First, the freeway conditions must be assessed. High congestion and high accident rate at freeway merge areas are typical examples favoring ramp-metering applications. The expected benefit from ramp metering should outweigh the associated costs. Ramp conditions should have adequate geometry to accommodate the

ramp metering components. Alternative routes should be examined and the potential impact on the surface street system should be addressed such as traffic diversion and queue spillback. Transit accommodation should be carefully studied and incorporated in the design process. The required funding resources must be secured. A good effort must be also made on public education to gain support from the public.

The system planning process includes determination of the type of ramp metering system, and the planned system architecture. Although easy to design and operate, fixed time ramp metering may not achieve the expected improvement on freeway operations. Fixed time metering may only be applied when traffic flow patterns are easily predicable, or at an isolated ramp location where breaking up the platoon flow is a major objective. At a minimum, local traffic responsive ramp metering is recommended since this type of ramp metering does not involve a significantly higher capital cost compared to the fixed time ramp metering. The operation of traffic-responsive ramp metering can be easily implemented since most modern traffic controllers are equipped with the required features to operate traffic-responsive metering. For example, the NEMA-type ramp-metering controllers manufactured by Eagle Systems (*17*) have built-in traffic-responsive ramp-metering algorithms. The 170/2070-type controllers have an open architecture, which allow users to develop and implement their own routines. Traffic-responsive metering can react to freeway condition changes in real time, thus is more cost effective compared to fixed time ramp metering. A higher level ramp-metering system is the coordinated ramp-metering system, which involves centralized control and coordinated operations among each individual ramp in the system. A central computer is required in such systems to be able to communicate with each individual ramp controller to perform download (i.e., system metering rate to local controller), upload (i.e., local volume, occupancy and speed information to central computer), and override (i.e., system override, queue override) functions. Upgrading to coordinated ramp-metering system is better accommodated with other ITS deployment projects. Ramp-metering systems should be integrated with other ATMS components, such as Incident Management, and Advanced Traveler Information Systems.

System design for a coordinated ramp-metering system includes geometric design of the metering ramps; selection of hardware, software, and communication technologies; and selection or development of a coordinated control system with supporting algorithms. It is important that any hardware devices and the software to be implemented have been fully tested to meet the required specifications. A latest product may have many advanced features, but it may not meet the requirements for the planned ramp-metering system. A good example is an integrated ramp metering system in California, where the 2070 controllers failed to meet many specifications (*10*). It is recommended that NTCIP compliant devices be used in all future deployments. Selection of a control system with appropriate control algorithms should be based on good understanding of the features of available control systems and algorithms. The details of some of the implemented coordinated ramp-metering algorithms are discussed in the next section.

System implementation would involve on-line testing of the system to make sure it is fully functioning. The system needs to be calibrated based on field conditions to derive the appropriate operating parameters. The calibration process can be very time consuming, which will depend on how well the control algorithm is designed, the documentation and instruction to operate the system, and the knowledge and skills of the operating staff. Once the system is fully functioning and the operating parameters are well established, a system performance evaluation is usually required. The recommended process for conducting system evaluation is provided in a later section.

It is important to emphasize that a great effort must be made to operate and maintain the system. Dedicated staff with good experience and knowledge of ramp metering must be available to monitor the system on a day-to-day basis. Good system documentation is critical in the current working environment where constant changing of staff is seen as usual. The system must be closely monitored for any malfunctions, and the system should be continually refined based on traffic flow changes.

In summary, the following key points highlight the entire system design and implementation process:

- A feasibility study should address issues related to traffic flow conditions, ramp conditions, surface street system configurations, transit operations, funding resources, and public education and support.
- Ramp metering should be designed to at least operate at local traffic-responsive level.
- Coordinated ramp metering system should be accommodated with other ITS deployment projects, and should be integrated with other ATMS components.
- The hardware, software, and communication technologies must have been fully tested to meet the required specifications.
- Selecting the control system or algorithm should be based on fully understanding of the operational features of the algorithm, the system configurations, the operating objectives, and the expected operating and maintenance level.
- The system should be tested before full implementation. The system should be calibrated, maintained, and continually refined to achieve the best performance.
- Good documentation and staff education and training will be an important part of the system maintenance effort.

COORDINATED SYSTEM RAMP METERING ALGORITHMS

A coordinated ramp-metering system determines ramp-metering rates based on consideration of the entire system under control. Several coordinated ramp-metering algorithms have been implemented in the United States. Some algorithms are being proposed for implementation and new algorithms continue to be developed. This section provides an overview of the features of each algorithm. Selecting an appropriate algorithm is an important element for achieving the best success in ramp-metering operations. Jurisdictions should select the control algorithm based on thorough understanding of the features of each algorithm, the system configuration, the operating objectives, and the required staff level and operating skills.

Local traffic-responsive metering is usually an integral part of a coordinated ramp-metering system. Therefore, it is necessary to have a better understanding of the local traffic-responsive ramp-metering algorithms. In a coordinated ramp-metering system, the metering rate at each individual ramp is usually the most restrictive between the system metering rate and the local traffic-responsive metering rate. In this section, two types of traffic-responsive metering algorithms are first described, followed by discussions of various policies on queue override, which is a major component of local traffic-responsive operations, and finally, some of the representative coordinated ramp-metering algorithms are described.

Local Traffic Responsive Ramp Metering Algorithms

Local traffic responsive ramp metering determines ramp-metering rate based on current freeway mainline conditions through the use of various mainline detectors. Therefore, ramp metering can react to condition changes in freeway, and is more effective than the fixed ramp metering system. Many traffic-responsive ramp-metering algorithms have been developed. Each algorithm may incorporate different detector design and operating policies. For example, mainline detectors can be located either upstream or downstream of the merge or both. The control algorithm may use speed, volume, density or occupancy as operating parameters. Volume is normally not used as a major parameter in the algorithms since volume is not a good indication of congestion. Occupancy and speed are the most commonly used parameters in various traffic-responsive ramp metering algorithms since both can be directly obtained from mainline detectors and they directly reflect the freeway conditions. Ramp queue detectors are usually an integral part of the ramp-metering system (18). Queue detectors are used to detect queue spillback conditions onto the surface street, and the majority of the states adopt some kind of policies regarding queue spillback. The following describes two types of traffic-responsive ramp-metering algorithms, which are mostly encountered in field implementations.

Local Feedback Algorithms

Such algorithms determine the metering rate in the current time step based on measurements from the mainline detectors from the previous time step. The most commonly used mainline detector data is occupancy since occupancy is a direct indication of mainline congestion. Some algorithms may also use speed and traffic volumes as additional parameters. Detector information may be from the upstream detectors, or the downstream detectors, or both. Ramp metering rate is usually determined based on predefined rate tables. Equation (1) shows the basic principle of such algorithms.

$$M(t) = f[O(t-1), S(t-1), V(t-1)] \quad (1)$$

where

- $M(t)$ = metering rate in the current interval
- $O(t-1)$ = mainline occupancy measurement from the previous time interval
- $S(t-1)$ = mainline speed measurement from the previous time interval
- $V(t-1)$ = mainline volume measurement from the previous time interval
- $f()$ = a function of O , S , and V

The metering rate is controlled so that the mainline occupancy (or speed and volume) will not exceed the predefined threshold values. Obviously, the threshold values need to be calibrated, which are related to detector locations, detector configurations, and operating policies (to what level congestion needs to be controlled). Most of the traffic-responsive ramp-metering algorithms in the United States are based on similar principle shown in Equation 1.

FUZZY Logic Based Algorithms

Another type of ramp metering algorithm was developed based on fuzzy logic. One of the noticeable developments in such algorithms is the one developed at the University of Washington (19). Fuzzy logic emphasizes qualitative information over quantitative information. Fuzzy logic based algorithm is designed to overcome some of the limitations of conventional ramp-metering algorithms. In the transportation field, there is a wide range of traffic and transportation engineering parameters, which are characterized by uncertainty, subjectivity, imprecision, and ambiguity. Transportation professionals use subjective knowledge (something hard to quantify) on a daily basis when making decisions. Fuzzy logic algorithm fits well in this category by applying the combined subjective knowledge and objective knowledge, therefore, a large amount of information can be incorporated in the algorithm. The fuzzy algorithm developed at the University of Washington has been implemented in the great Seattle area, and field testing and evaluation have shown that it resulted in improved operations over the traditional local traffic-responsive algorithms (20). The algorithm uses seven detector inputs including downstream occupancy, downstream speed, upstream occupancy, occupancy at merge, speed at merge, queue occupancy, and advanced queue occupancy.

The key components of the fuzzy logic ramp-metering algorithm include the fuzzification process, a set of fuzzy rules, and the defuzzification process. Fuzzification is to convert the detector measurements into one of five different textual classes – *very small*, *small*, *medium*, *big*, and *very big*. These “fuzzified” inputs are then run through a rule-base (IF-THEN rules), similar to the one shown below to determine a control action:

[IF *very small* AND *queue* THEN *high metering rate*]

The textual control actions obtained are then subjected to “defuzzification” to produce real-number metering rates or metering parameters in the controller.

The fuzzy logic algorithm has several advantages over other ramp metering algorithms. It does not require extensive system modeling, as freeway systems are usually difficult to model due to the nonlinear and non-stationary nature. Calibration of the algorithm is also relatively easy. Fuzzy logic algorithm can still function by using partial or imprecise information, while other algorithms are sensitive to detector error because they calculate metering rate directly from raw data.

Queue Override Policies at Metered Ramps

Queue detection at metered freeway on-ramps is usually a critical element for ramp metering design and operations. While different states have different guidelines on where the queue detectors should be located (18), the primary purpose of queue detection is to minimize queue spillback to the surface street system. Various policies have been adopted in different states regarding ramp metering rate adjustment when queue spillback is detected. Table 3 is a summary of the policies.

As can be seen from Table 3, the majority of the states use queue detectors and adopt the policy to flush the queues by either increasing the metering rate or shutting-off the ramp metering. Since shutting-off ramp metering will diminish the primary objective of ramp metering, it is thus recommended that increasing rate policy be adopted in metering operations. However, shutting-off metering may be necessary during incident and high diversion cases (3).

Table 3. Queue Detection and Ramp Metering Policies

State	Use Queue Detector	Criteria for Queue Detection (occupancy & duration)	Metering Policy
Arizona	Yes	75%	Increase metering rate
Minnesota	Yes	25%, 30 seconds	Increase metering rate
Texas	Yes	10 seconds	shut-off
Washington	Yes	Unknown	Increase metering rate
Colorado	Yes	15% - 80% occupancy	shut-off
California	Yes	occupancy threshold >2 minutes	Increase metering rate
Wisconsin	Yes	10%~80%	Increase metering rate
Oregon	No	N/A	Avoid spillback through metering rate design
Utah	No	N/A	No policy yet
Illinois	Yes	Unknown	Increase metering rate
Georgia	Yes	Unknown	Increase metering rate, shut-off
Michigan	Yes	Two Levels (unknown)	L#1: Increase metering rate, L#2: shut-off
Virginia	Yes	Unknown	Increase metering rate, shut-off

Coordinated Ramp Metering Algorithms

Various types of coordinated ramp-metering algorithms have been developed and implemented in several metropolitan areas. Although each algorithm varies in its features and functions, the basic principle of each algorithm is similar, i.e., to control the metered ramp flows so that the total freeway traffic demand does not exceed the bottleneck capacity. The most commonly used algorithms are based on real-time information from freeway mainline detectors. Speed, occupancy, density and traffic volumes are typical parameters in such algorithms. Examples of such algorithms include SWARM (21) in Los Angeles, California, Portland, Oregon, and Chicago, Illinois; BOTTLENECK (22) in Seattle, Washington; ZONE (23) in Minneapolis, Minnesota; and HELPER (6) in Denver, Colorado. Another type of ramp metering algorithms is based on the optimization principle of linear programming. The objective function is to maximize total ramp entry flow or total vehicle miles travel subject to a set of operational constraints. Such algorithms typically require extensive data collection efforts including Origin-Destination (OD) information, which is always a challenge for real-time control systems. Examples of such ramp metering algorithms include RAMBO II (24) proposed in Arlington, Texas and MILOS (25) in Phoenix, Arizona. Linear-programming based algorithms are not discussed in this paper, since both algorithms have not yet been implemented in the field.

Figure 5 represents the general structure for most on-line real-time coordinated ramp metering algorithms. As illustrated in Figure 5, a coordinated ramp metering system typically consists of two components: a system wide control algorithm and a local control algorithm. The entire ramp-metering system may be divided into control zones or groups with the coordinated control algorithms being applied to each zone. The coordination algorithm is to achieve a metering rate at each on-ramp so that a system optimal objective can be met. The system objective is to maximize the freeway throughput without causing bottleneck congestion. The local control algorithm is to achieve a metering rate based on local conditions at each ramp. The majority of local control is traffic-responsive metering. The metering rate at each ramp is determined based on the most restrictive one (the lowest rate). The final metering rate is subject to the maximum and minimum metering rates as well as other adjustments such as queue override. Depending on the operating policies on queue override, queue spillback can result in an increased metering rate or metering suspension. The following discussions focus on the features of some of the system control algorithms being implemented in different metropolitan areas in the United States.

Seattle's Bottleneck Algorithm (22)

The algorithm was first implemented in 1981 on I-5, north of the Seattle central business district. The algorithm has three components: calculation of metering rates based on local conditions, calculation of metering rates based on system capacity (bottleneck) constraints, and adjustment to the metering rates based on local ramp conditions. Metering rates are calculated for each ramp every 20 seconds based on 1-min accumulations of volume and occupancy. The local metering rate is based on traffic-responsive operation, and the metering rate is determined based on occupancy from the mainline detectors located upstream of the ramp. The system's metering rate is determined based on capacity conditions of each freeway section. A freeway section is defined by two adjacent mainline detector stations, approximately 0.5 miles apart. Whenever the occupancy from the mainline detectors exceeds the predefined threshold (about 18 percent), it is assumed that the section reaches its capacity. The total entering volume as well as the total exiting volume of the section is also checked constantly (in 1 min interval) to see if there are any vehicles stored in the section. The section is considered to store vehicles whenever the total existing flow is less than the total entering flow. When both the capacity condition is reached and there are vehicles stored, the required volume reduction to the upstream entrance ramps is calculated, which equals to the difference between the total entering volumes and the total exiting volumes. Each freeway section is assigned an *influence area*, which is a tunable parameter and is defined by the number of upstream

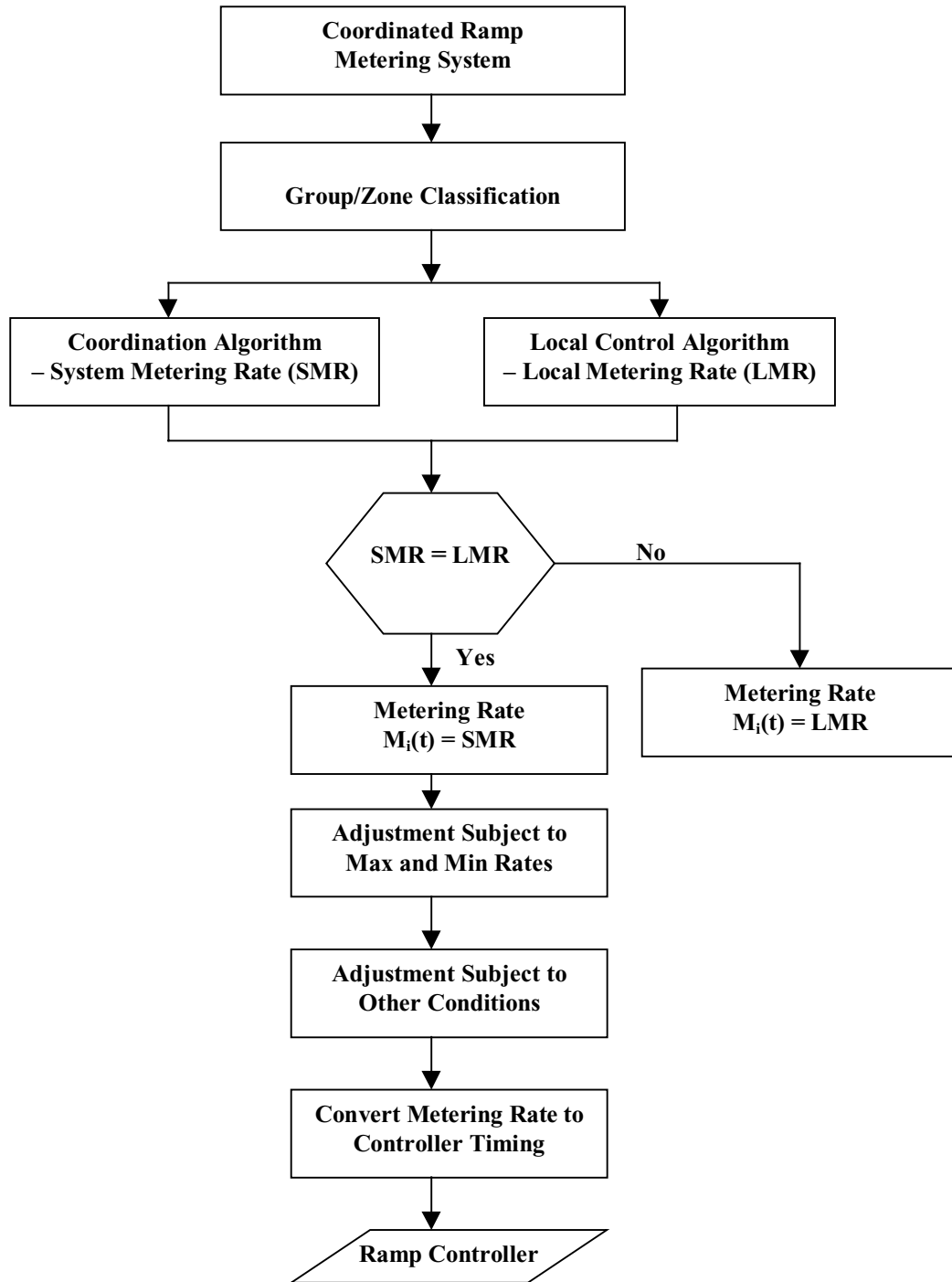


Figure 5. Flow Chart for Coordinated Ramp Metering Systems based on Bottleneck Control

ramps that are affected by the bottleneck metering rate calculation for the subject freeway section. The required volume reduction is distributed to all the ramps within the influence area on the basis of the weighting factors assigned to each ramp. The weighting factor is usually determined based on the distance to the bottleneck location and the traffic demand. For example, a larger weighting factor is assigned to those ramps that are closer to the bottleneck or have higher traffic demand. Therefore, volume reduction is more profound for those ramps closer to the bottleneck and with higher traffic volumes. The final metering rate is then determined based on the traffic volume counts from the previous 1-min interval minus the calculated volume reduction. The system begins the calculations from the upstream end of the control area. There might be overlaps among areas of influence, thus any ramp may have several bottleneck metering rates calculated for it. Only the most restrictive metering rate is selected. The metering rate obtained from the above steps is also subject to the following adjustments:

- Metering rate needs to be increased if actual ramp volume is less than desired, which is caused by driver's inexperience or inattention that missed the green to enter.
- Metering rate needs to be reduced if the ramp volume is higher than expected, which is caused by HOV vehicles or violations.
- Metering rate will also increase if the advanced queue detector is occupied for a specified length of time. Sometimes, the rate can increase to the maximum rate of 15 vpm (900 vph). With 900 vph metering rate, the queue should be cleared eventually since the ramp demand should be less than this number, otherwise, metering should not be implemented at this location.
- The final metering rate must be within the minimum and maximum metering rates.

Minnesota's Zone Algorithm (23)

The ramp metering system in the Twin Cities, Minnesota has gone over 30 years of development, and is one of the most advanced coordinated ramp-metering systems in the United States. The coordinated ramp-metering algorithm is called the *Zone Algorithm*, developed by the Minnesota DOT. The algorithm has been extensively tested and calibrated over many years of operations. The basic principle of the algorithm is to operate the ramp metering based on control zones, with each zone typically covering a 3 to 6 miles freeway section. The beginning or upstream end of a zone is usually a free-flow area not subject to congestion. The downstream end of a zone is usually a bottleneck, typically a section with lane drops, high volume entrance ramps, or high volume weaving sections. A zone may have several on-ramps and off-ramps where the on-ramps can be either metered or non-metered. The metering rate is set so that the total entering flow to the zone is less than the total exiting flow from the zone. Equation (2) illustrates the relationship between all the variables in a zone:

$$M(t) + F(t) = B + X(t-1) + S - A(t-1) - U(t-1) \quad (2)$$

Where

- $M(t)$ = total metering volumes of all the metered ramps for the current time interval
- $F(t)$ = metering volume for freeway-to-freeway connector for the current time interval
- B = bottleneck capacity, a predefined value
- $X(t-1)$ = total exiting volumes of all the off-ramps measured from previous time interval
- $S(t-1)$ = spare capacity to store vehicles, calculated based on free-flow density and measured from previous interval
- $A(t-1)$ = upstream mainline volume measured from previous time interval
- $U(t-1)$ = total non-metered ramp volumes measured in previous time interval

All the above variables (except for S) are expressed as 5-minute flow rates. $M(t)$ and $F(t)$ are controlled variables, representing the target metering rates (or the maximum allowable entering volumes) for the metered ramps and freeway connectors. The total target metering rate for all the ramps, $M(t)$ is then distributed among all the metered ramps based on the ratio of the demand at each ramp to the total

demand (measured volumes from previous intervals). The actual metering rate at each ramp is governed also by the minimum and maximum metering rates.

The zone algorithm has an incident override feature. The occupancies from mainline stations (spaced at 0.5-miles) for the latest 30 second periods are recorded in directional order through the zone. A comparison is made every 30 seconds of successive station occupancies. If any pair of successive stations show a drop in occupancy of more than 25 percent, then all ramp meters in the zone downstream from the pair of stations where the drop occurred are set to a zone incident override rate, which is at least the target metering rate.

The earlier zone algorithm (before 2000) did not have a queue override feature at the on-ramps. A recent revised policy on ramp queue is to allow a maximum 4-min delay on the ramp. An increased ramp-metering rate can override the system's metering rate to allow quick release of the ramp queues. Adoption of such queue override policy is to address the concerns raised by the public during a recent system evaluation study (26).

Denver's HELPER Algorithm (6)

The first ramp metering application in Denver, Colorado was in 1981. System expansion started in 1984. By 1988, a centralized coordinated ramp-metering system was in operation with a total of 24 ramp meters. By 2002, the total number of metered ramps under centralized control reached 44, located on freeway segments on I-25, I-225, I-70, and C470. The HELPER algorithm, also known as the *Denver Ramp Metering Control Software* was developed by JHK Inc. (14). The algorithm consists of a local traffic responsive metering algorithm and a centralized coordinated override feature. Similar to the ZONE algorithm, the ramps being controlled are divided into groups, with one to seven ramp meters assigned to each group. Within the local responsive algorithm, each meter selects one of six available metering rates based on localized upstream mainline occupancy. Ramp presence and passage detectors are used to detect vehicles waiting and clearing the ramp signals. Ramp queue detectors are used and a queue presence overrides the normally selected metering rate. Increased metering rates are implemented until excessive ramp queues are cleared. The algorithm also incorporates an exponential smoothing function to prevent wide swings in metering rates during concurrent time intervals.

At the coordinated control level, the central computer monitors and collects detector and metering data from each ramp controller every 20 seconds. If a ramp is in the most restrictive rate (freeway congestion) or in a queue override mode, the ramp is defined as critical. When a ramp is classified as critical, the centralized control immediately begins to override upstream ramp meters. A more restrictive metering rate is applied to the next upstream ramp. If the ramp remains in critical condition during the next sampling interval, the rates of the next two upstream ramps are forced one rate more restrictive. The system continues to add ramps to the centralized control during each sampling cycle until all ramps in the group are under central control. If more than one ramp becomes critical, multiple central control plans are put into effect.

California SWARM Algorithm (21)

The SWARM (System Wide Adaptive Ramp Metering) was initially developed by National Engineering Technology (NET) for Caltrans District 12 as part of an effort of integrated corridor control (10). The SWARM algorithm consists of two components: SWARM 1 – a forecasting and coordinated ramp-metering algorithm; and SWARM 2 – a local traffic responsive ramp-metering algorithm. One of the unique features of SWARM 1 is its forecasting function, a proactive methodology for anticipating freeway congestion. The algorithm operates in the following manner:

A freeway network is divided into control sections (4 ~ 7 miles). Sections are established based on known bottleneck locations at their furthest downstream point. The SWARM 1 algorithm controls all

upstream entrance ramps in the section to not exceed the bottleneck capacity. Instead of using occupancy, density is the control parameter of SWARM 1, since density is also directly related to congestion, but it is easier to forecast than occupancy. The algorithm requires a nominal density threshold value named *saturation density* for each detection station. Saturation density levels are dynamically computed and updated for each station in real time. It uses linear regression and a Kalman filtering process to forecast a density trend at each detector station for each time interval. The time into the future to forecast (T) is a tunable parameter. From the forecasted density, an “excess density”, or density above the saturation density, is determined. This value is used by SWARM1 to determine how much to reduce traffic density at that location to prevent congestion. The required density or target density is then converted to volume reduction, which will determine the ramp metering rates. SWARM1 uses 30-sec interval to update the calculations. While the overall approach of the ramp-metering algorithm is similar to the BOTTLENECK and ZONE algorithms, SWARM also incorporates a failure management and data enhancement system for checking detectors against historical trends to identify any failures and eliminate data “noise”. This ensures that the system will still function properly due to detector failures.

A Comparison of Coordinated Ramp-Metering Algorithms

- All the algorithms discussed in this section use real-time information from detectors, and are subject to similar limitations. First, no OD information is available and used. Therefore, the calibration and operation of the algorithm rely on similar OD patterns. A problem facing the lack of OD information is that vehicles entering from a ramp may not go through the bottleneck where the control is applied. Therefore, applying volume reduction to those ramps may be too restrictive.
- Since the metering rate is usually determined based on previous intervals (e.g., 20 seconds), there is a time lag between when the problem is detected and when the actions taken can have a positive impact. This creates problems when the system could only recover after the peak period is over. An example is the cycling between queue override and metering rate reduction. When the metering rate needs to be significantly reduced, a queue will form on the ramp, thus resulting in queue override. Freeway operations deteriorated when queue override takes over.
- All the algorithms have a local traffic-responsive metering component, where the metering rate is selected from the most restrictive of the local metering rate and the system’s metering rate. The final metering rate is also subject to queue override and minimum and maximum values. The BOTTLENECK algorithm also applies other adjustments such as HOV vehicles.
- The majority of the algorithms use occupancy and volume as control parameters. However, SWARM uses density as a control parameter due to the fact that there are well-established density-flow models. Forecasting on density also appears to be easier than forecasting on other parameters. Most of the data are obtained from mainline detectors spaced at about 0.5-mile intervals, and from the ramp detectors.
- The ZONE algorithm uses the most extensive data sources, including detectors located on non-controlled ramps and off-ramps.
- The BOTTLENECK and SWARM algorithms use variable control zones, while the ZONE and HELPER algorithms use fixed zones. The BOTTLENECK, ZONE, and SWARM algorithms apply control simultaneously to all the ramps within a zone or a control area, while the HELPER algorithm applies control one at a time upstream of the critical ramp location, which may not be as effective to prevent system congestion.
- While SWARM algorithm has some unique features over other algorithms such as the forecasting and failure management functions, it has not gone through extensive field test compared to the other algorithms. In fact, the only implementation test in California indicated that SWARM did not function as expected (*10*). Some of its components required redesign. For example, at the time of testing, SWARM could only implement one ramp at a time as opposed to section by section. The lack of permanent memory to store the setup parameters would require that all ramp parameters be re-entered once SWARM was turned off. Due to these problems, the effectiveness of the system was not being able to be evaluated.

SYSTEM PERFORMANCE EVALUATION

System performance evaluation is to address the effectiveness of a ramp-metering system, and is considered as a major task of the entire implementation process. An appropriate evaluation procedure is necessary to assist state and local agencies in successfully conducting the evaluation process. This section addresses the procedures for conducting system performance evaluation, the recommended performance measures to be used in the evaluation, and the methodology of conducting benefit/cost analysis.

System Performance Evaluation Procedures

A comprehensive ramp-metering system evaluation involves many tasks. These tasks should be carefully executed in order to meet specific objectives in a timely manner. Figure 6 is a recommended procedure for conducting ramp-metering system evaluations. This recommendation is basically a representation of the evaluation process used in the Twin Cities study (26).

Establishing a high quality team is the first step for a successful system evaluation. The team should include an advisory board and a technical group of staff. The advisory board serves as a role to provide policy oversight, input, and guidance to the project and to provide overall quality control. The advisory board members may include legislators, local government representatives, researchers, engineering expertise, industry representatives, and stakeholder representatives. The technical group should be formed by independent consulting firms, specializing in system analysis, data collection, and market research.

Once the project team is established, the study goals and objectives must be identified. To achieve a specific objective, a set of performance measures must be established to provide quantitative or qualitative evaluations of the objective. For example, to achieve the objective of quantifying ramp metering impact on freeway traffic flow, several performance measures may be used, including travel time, travel speed, traffic volume throughput, and travel time reliability. Table 4 is an example of the evaluation objectives and their associated performance measures. The details of various recommended performance measures are described in the next section.

Table 4. Evaluation Objectives and Associated Performance Measures

Evaluation Objectives/Aspects	Performance Measures
Impact On Freeway Traffic flow	travel time, travel speed, travel time reliability, traffic volume
Impact on Ramp Operations	delay, queue length, queue spillback, travel time reliability
Impact on Safety	accident types and rates, traffic conflicts, HOV lane violations, speed variations
Impact on Environment	emissions, fuel consumption, noise
Impact on Transit Operations	transit travel time, ridership, operating costs, park-and-ride rate
Impact on Arterial Traffic Flow	traffic volume diversion, ramp queue length
Benefits and Costs	capital investment, operating costs, maintenance, management, research and development

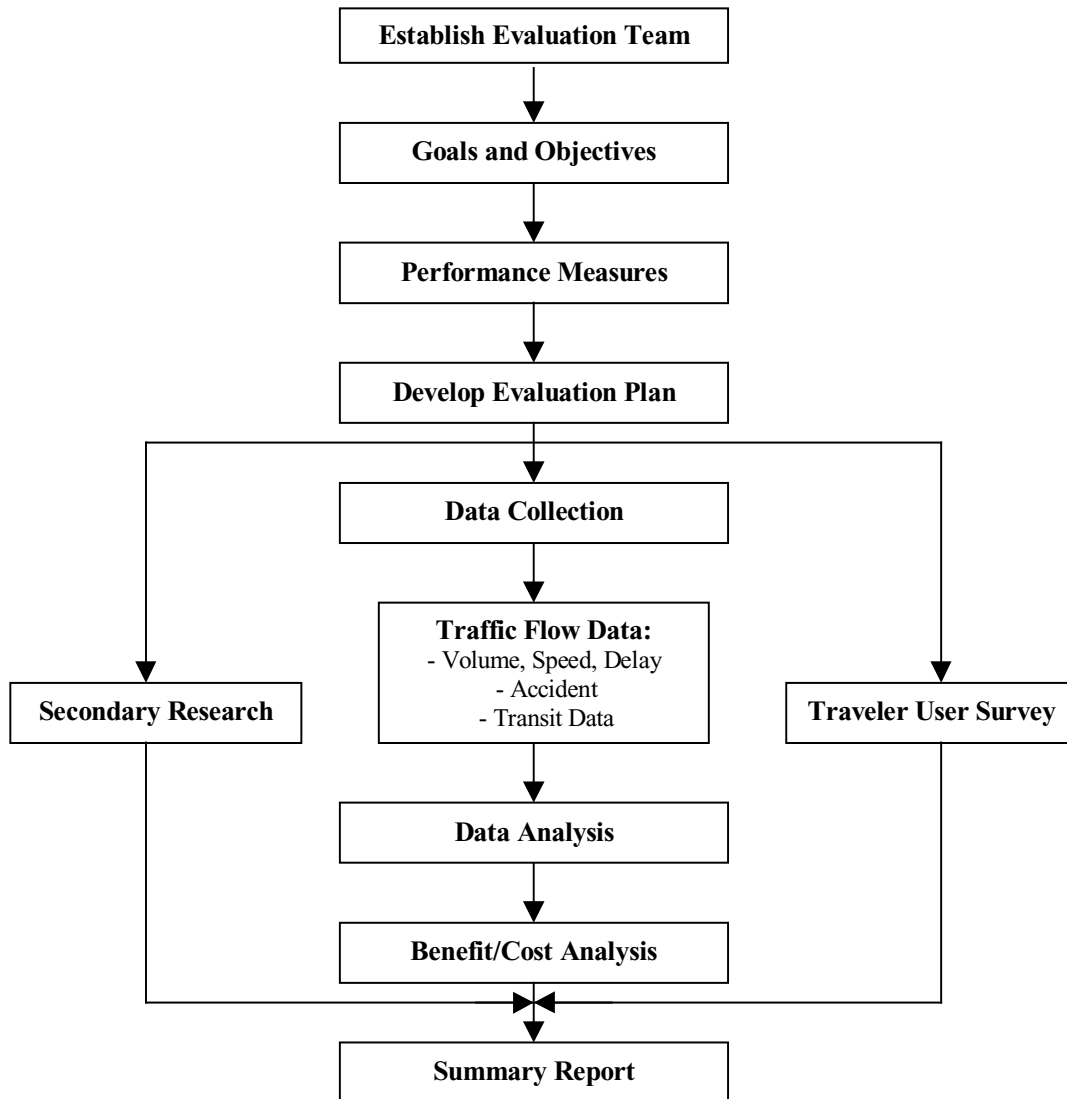


Figure 6. Recommended System Performance Evaluation Procedures

An evaluation plan with detailed scheduling of each major task should be established before major data collection is initiated. Other study tasks, such as secondary research task and user group survey can be carried out parallel to the data collection of traffic flow, accident, and transit operations. The secondary research task is to gather information from other studies to make sure the outcome of the study is within a reasonable range.

Data collection and data analysis tasks require the most extensive resources for the entire evaluation process. There are various issues that need to be considered during the data collection and data analysis tasks. Define the scope of data collection and select representative corridors or corridor segments are critical since collecting data on the entire system may be too expensive. A good practice is to concentrate

on a few corridors or corridor segments from which the area wide results can be interpolated. For example, the study conducted at the Twin Cities of Minnesota (26) involved 430 ramp meters and 210 miles of freeways. Data collection was only carried out at a few representative corridors consisting of different types of facilities. Four types of corridor facilities were classified as shown below:

- **Type A:** with high percentage of commercial and recreational traffic. Commuter traffic is generally from suburb to suburb
- **Type B:** corridor with geographic constraint that does not allow for alternative routes (e.g., river crossing)
- **Type C:** Inter-city connector that carries traffic moving between major business and commercial zones. This type freeway has a fairly even directional split of traffic throughout the a.m. and p.m. peak periods
- **Type D:** Radial freeway that carries traffic to/from a downtown or suburban work center

All the freeways were then categorized based on the above four types. Corridors not fitting completely within a single category were assigned to two or more categories using percentages.

Another critical issue for data collection is the selection of time frame for before and after studies. It is recommended that the before data (without metering) be collected right before the new system is put into operation. This would avoid comparing incompatible traffic data sets resulted from long time span, where the traffic demand, the traffic patterns, and the roadway network may have significantly changed. Data collection on traffic flow should also avoid situations such as incident and bad weather where the data may not reflect normal system operations. To ensure the data is statistically valid, enough samples of data must be collected, which is determined by the required accuracy level and confidence level. In general, a 95-percent confidence level is used in conducting engineering studies. Data analysis must be performed using appropriate analysis tools. The analysis tools may include spreadsheet models or commercial software packages. Normal growth and seasonal variations must be taken into account while comparing results from before and after studies. Sensitivity analysis, statistical tests are necessary to yield valid results. Once all the data is gathered and analyzed, the final analysis product is to conduct the benefit/cost analysis, which will be addressed later in the paper.

Performance Measures

A comprehensive system evaluation should be based on well-established performance measures to reflect the various aspects of the system. The following describes the recommended performance measures based on both literature review and agency interviews. These recommendations are based on the fact that the performance measures are of significance, but are also easily obtainable.

Freeway Mainline System

- **Travel Time and Travel Speed** – Travel time and travel speed are good indicators of freeway conditions. Lower travel time and higher travel speed are expected through ramp metering. While travel time can be better perceived by the general public, it is more difficult to measure in real time. However, travel time can be estimated based on travel speed, which can be directly obtained from mainline detectors. Other ITS technologies can be also applied to estimate travel time, such as the application of Automatic Vehicle Identification (AVI) technologies (27).
- **Travel Time Reliability** – a measure of the expected range in travel time, calculated by the standard deviation of travel time. It is a quantitative measure of the predictability of travel time. Travel time reliability is a more appropriate quantitative measure to reflect unexpected non-recurring delays due to incidents, special events, bad weather, or excessive congestion. Being on time for day care, a meeting, a flight, or delivery are typical examples of commuter expectations for reliable travel time.
- **Travel Speed Reliability** – a measure of the travel speed variations to reflect the safety aspect of the freeway operations. Similar to travel time reliability, travel speed reliability can be obtained based on

the standard deviations of speed. Travel speed reliability is a good indicator of freeway stop-and-go situation, which is a major contributor to rear-end collisions.

- Traffic Volume or Throughput – a measure of improved freeway system capacity. When traffic volume or throughput is measured during congested flow region (speed at or below capacity level), it reflects the freeway capacity. Increased traffic throughput is expected through successful ramp metering operations.

Metered Ramp

- Metering Reliability – a measure to evaluate how well the targeted metering rate (established through either local traffic responsive or system control) is maintained. It is calculated as the percentage of time the targeted metering rate is maintained during metered conditions. Increased metering rate during queue override is an example when the targeted metering rate is violated.
- Metering Availability – a measure to evaluate how metering operation is maintained without metering shut-off. This performance measure mainly applies where queue detectors are used and queue flush policy is adopted. It is the percentage of time when the metering is not in queue flush (metering shut-off) operation. Good quality metering system is to achieve higher metering availability.
- Ramp Queue and Delay – performance measures to evaluate the adverse impact imposed on the ramp users. Excessive delay to the ramp users is likely to result in driver frustration and violation. Excessive queue may impose safety concerns to the surface street.

Safety

- Accident Type and Rate – a measure to directly reflect the safety aspects of ramp-metering operations. Ramp metering is expected to significantly reduce side-swipe and rear-end accidents.

Environment Impact

- Emissions – a measure of increasing or decreasing in hazardous emissions such as hydrocarbons, carbon monoxide, and nitrous oxides. Calculations of different types of emissions are usually based on established models relating to travel speed. Therefore, different types of emissions may increase or decrease due to ramp-metering applications.
- Fuel consumption – a measure of increasing or decreasing in fuel consumption related to ramp-metering applications. Fuel consumption is also calculated based on established models relating to speed, acceleration and deceleration.

Transit Operation

- Transit Ridership – a measure of changes in public transit ridership or carpool ridership. When HOV by-pass lane is equipped at the ramp metering locations, ramp metering will likely result in transit ridership increase.

Benefit/Cost Analysis

Benefit/cost analysis of ramp metering systems largely depends on the various performance measures for the before and after metering cases. Performance measures can be obtained either from field evaluation studies (implemented systems) or through simulation (planned systems) (28,29). Although simulation models have shown promising results in obtaining more detailed performance measures and providing the flexibility in modeling different traffic flow and ramp metering control scenarios, simulation models may not well reflect the actual system performances due to limitations in modeling complex systems. It is recommended that actual performance measures from the field be used to conduct the benefit/cost analysis if the system is in operation, however, simulation may be used as an alternative tool for further investigation of other traffic and control scenarios.

Benefit/cost analysis involves the following steps: quantify all aspects of the performance measures; identify the associated capital, operating, and maintenance costs; determine life cycle; convert to current year values; and calculate benefit/cost ratio. The benefits and costs of ramp metering systems are summarized below:

Benefits (area wide measures, including freeway and surface streets)

- Travel Time Saving
- Travel Time Reliability Improvement
- Accident Reduction
- Reduction in Emissions
- Reduction in Fuel Consumption

Costs (ramp metering system related)

- Construction Cost
- Operating and Maintenance Cost

Quantification of performance measures is a key element of the analysis. All performance measures must be represented by monetary values, which are dependent on geographical region and socioeconomic developments. Table 5 is an example of the values assumed in the Twin Cities study (26).

Table 5. Assumed Unit Values for Performance Measures

Performance Measures	Unit	Value
Travel Time Saving	Person Hour	\$9.85
Travel Time Reliability	Person Hour	\$9.85
Fatality Accidents	Per Accident	\$1,176,584
Severe Injury Accidents	Per Accident	\$57,287
Moderate Injury Accidents	Per Accident	\$21,711
Minor Injury Accidents	Per Accident	\$13,471
Property Damage Only	Per Accident	\$6,789
Hydrocarbons	Per ton	\$1,774
Carbon Monoxide	Per ton	\$3,731
Nitrous Oxide	Per ton	\$3,889
Fuel Consumption	Per gallon	\$1.45

Source: Reference (26)

Estimating the costs directly associated with a ramp metering system may be difficult when the system is implemented as a portion of an overall ITS deployment project. A recommended approach is to first estimate the proportion of the ramp-metering element over the entire ITS components, and then allocate the proportion of ramp-metering system. The calculated benefits and costs in monetary values must be converted into an annual basis at current year values assuming an expected rate of return (e.g., 5 percent) and the expected life span (e.g., 10 years). Equations 4 to 6 can be used for benefit/cost ratio calculations.

$$B/C = \frac{\sum_k^K PVB_k}{\sum_k^K PVC_k} \quad (3)$$

$$PVB_k = \frac{B_k}{(1+i)^k} \quad (4)$$

$$PVC_k = \frac{C_k}{(1+i)^k} \quad (5)$$

where

B/C	= benefit/cost ratio
PVB_k, PVC_k	= present value of benefit and cost in year k
B_k, C_k	= benefit and cost in year k
K	= expected life span, 10 ~ 15 years
i	= expected rate of return, 5 percent ~ 10 percent

The Effectiveness of Different Types of Ramp Metering Systems

One of the expected products of this research was to compare the effectiveness of various types of ramp-metering systems. Table 6 is a summary of the various performance measures obtained from previous studies for different types of ramp-metering systems. All the results are based on field measurements from actual implemented ramp-metering systems (26).

In general, ramp metering resulted in improved operations across all the performance categories (fuel consumption increase in the Twin Cities area is the only exception). However, there seem to be no obvious differences in the performance measures for different types of ramp metering operations. There is a wide range of values for each of the performance measure in each category. For example, the travel time saving ranges between 7 percent and 90 percent. The speed increase ranges between 3 percent and 160 percent. The accident reduction ranges between 5 percent and 50 percent. The benefit/cost ratio ranges between 4:1 and 20:1. Although traffic volumes also showed increase after ramp metering implementations, cautions need to be made while making any conclusions. Traffic volume increase may be due to normal traffic growth, but not necessarily the result of system throughput (capacity) increase.

In fact, comparing the effectiveness of different types of ramp-metering systems must be based on the same traffic flow and network conditions. Strictly speaking, such an analysis could only be achieved through simulation studies. However, one field study (9) did roughly compare the effectiveness of traffic-responsive operations versus coordinated operations, and the conclusion was that if local traffic responsive operation could maintain freeway at free-flow speed, coordinated system would result in negligible improvement. A common sense is that congestion may not be effectively controlled by simply running local traffic-responsive ramp metering. When the objective is to prevent system congestion, coordinated ramp-metering system is probably the only solution.

Table 6. Comparison of Performance Measures for Different Types of Ramp Metering Systems

Location (Study Time)	Type	Performance Measures						
		T.T.	Speed	Volume (vph)	Accident (vph)	Fuel (gallons per day)	Ramp Delay	B/C
Twin Cities, MN (2000)	C	-22%	+7 mph	+14%	-26%	+22,000 gal/day	+2.3 min/veh	5:1 ~ 15:1
Seattle, WA (1987)	C	-47.7% ~ -91%	+20% ~ +25%	+62% ~ +86%	-38%	-	+3 min/veh	10:1+
Denver, CO (1982)	C	-26.7 ~ -37%	+35.5 ~ +58%	+19%	-5 ~ -50%	-	-	-
Detroit, MI (1988)	C	-7.4%	+8%	+14%	-50%	-	-	-
Long Island, NY (1987~1991)	C/R	-13 ~ -20%	+9% ~ +21%	0% ~ +7%	-15%	-6.7%	1.2 ~ 3.4 vehicles	
Milwaukee, WI (1995)	C/R	-	+3% ~ +35%	+22%	-	-	-	-
Los Angeles, CA (1975)	R	-13%	+15 mph	-	-20%	-13%	-	-
Sacramento, CA (1984)	R	-	-	+3% ~ +5%	-50%	-	-	-
Atlanta, GA (1997, 2001)	F	-10%	+11%	-	-	-	-	4:1 ~ 20:1
Arlington, TX (1999)	F	-10%	-	-	-	-	-	-
Austin, TX (1997)	F	-37.5%	+60%	+7.9%	-	-	-	-
Houston, TX (1997)	F	-22%	+29%	-	-	-	-	-
Phoenix, AZ ¹ (1989 ~ 1995)	F	-	+5% ~ +10%	+15%	-	-	-	5:1 ~ 10:1
Portland, OR ¹ (1982)	F	-7.4% ~ -39%	+7.5% ~ +155%	+25%	-43%	-540 ~ -700 gal/day	-	-

Notes: 1. Portland and Phoenix are upgrading to coordinated ramp metering systems, and system evaluations are underway.

2. C – Coordinated; R – Traffic Responsive; F – Fixed Time

SUMMARY OF RECOMMENDED GUIDELINES

This study addressed the various aspects related to coordinated ramp-metering systems. Guidelines were developed to assist state agencies in performing various tasks in the entire system deployment process. The following is a summary of the recommended guidelines of this research:

- A feasibility study should be conducted to determine whether a ramp metering system can be physically designed and operational effective. The analysis should focus on freeway traffic flow conditions, ramp geometry, surface street system characteristics, transit operations, funding resources, and public support.

- Determination of the type of ramp metering system should be based on the operational objective. At a minimum, a ramp-metering system should be designed to operate with basic local traffic responsive features. If system congestion control is the primary objective, coordinated ramp-metering system is then recommended. Multi-lane ramp metering should be designed where geometry condition allows, and bulk-metering operation should be used on ramp locations with high traffic demands.
- The system architecture of coordinated ramp-metering systems should be designed to integrate with other ATMS components, such as Advanced Traveler Information Systems, Incident Management Systems, and Dynamic Message Signs to achieve the greatest benefit and effectiveness.
- Selection of hardware devices, software and communication technologies must be based on thorough testing to meet the expected specifications. NTCIP compliant devices should be used for all future implementations.
- Selection of the control system or control algorithm must be based on thorough understanding of their operating principles and features. FUZZY logic based algorithms should be considered for local traffic-responsive metering. ZONE or BOTTLENECK algorithms should be used for coordinated ramp-metering operations. However, the SWARM algorithm should be considered once field evaluations on the existing systems prove to be operational effective.
- Queue detectors and appropriate queue override policies should be adopted in the ramp-metering system to balance the need for both the freeway system and the surface street system. Increasing metering rate is a recommended policy over the ramp metering suspension (shut-off).
- Coordinated ramp-metering systems may need to be implemented and tested in different stages. Ramp metering should be tested individually to be well functioning with local traffic responsive operations before coordinated ramp-metering system is put into full operation.
- A significant effort should be devoted to system calibration to identify the appropriate operating parameters. These parameters are unique to each location, thus need to be calibrated based on both individual locations and system considerations.
- A system performance evaluation should be conducted to document the effectiveness of the implemented system. The evaluation should be based on a set of established performance measures and similar traffic flow conditions for the before and after cases. To avoid a long time span, data collection for the before case may be conducted right before the system is put into full operation, or it may require to temporally turn the system off. Normal traffic growth and seasonal variations should be taken into consideration if data collection cannot be completed within a short time span.
- The system should be well documented, including system structure, operating instruction, and calibrated parameters. The system should be well maintained and monitored with designated staffs to ensure fully functioning. The system should be continually refined to accommodate traffic flow changes.
- A good effort must be also made on public education to gain continued support from the public.

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APPENDIX A – AGENCY SURVEY QUESTIONS

The following survey questions were sent to different State Department of Transportation persons as part of the research effort. Questions 1 – 8 were included in the original survey, and additional information was obtained through later communication with state agencies.

1. How many ramp-metering locations are there in your metropolitan area (List all metropolitan areas of your state if possible)?
Name of metropolitan area:

Number of Ramp Meters:
2. Indicate the number of ramp-metering systems by category:
 - A. *Fixed Time* - Isolated ramp metering with fixed metering rate and metering time period
 - B. *Local Traffic-Responsive* – Varied metering rate to reflect traffic flow conditions, but without interconnection between ramps
 - C. *Integrated System* – Interconnected between ramp-metering locations. Also indicate whether the system includes surface street arterial systems, and what system software is used.
 - Location of the system (e.g., I-5 between xx and xx)
 - Number of ramps interconnected
 - Yes, including arterial signals
 - No, does not include arterial signals
 - Name of system software, vendor or software developer name (e.g., SCAT, SWARM, FUZZY-LOGIC, BOTTLENECK, ZONE, RHODES)
 - Describe approach or the concept of your integrated system, i.e., size of integrated segments, detector placement, etc
3. Do you plan to implement traffic-responsive or integrated ramp-metering systems as described in (B, C of Question 2)?

If YES, provide planned time and number of ramps for implementation
4. What are the operating policies on queue spillback to surface street resulted from ramp metering (e.g., no more than 2 min delay, flush queue)?
5. List the key elements for a successful ramp-metering operations (e.g., public education, agency coordination)
6. List the key issues which hindered ramp metering implementation and operations (e.g., political issues, software functions)
7. What are the major system-performance measures for evaluation of ramp-metering systems?
8. Do you have any ramp-metering related documents that I can obtain (printed, website, meeting memos)? More specifically, those documents related to system evaluation and benefit-cost analysis.

ZONG TIAN

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Tian was the primary researcher on the NCHRP 3-46, Capacity and Level of Service at Unsignalized Intersections, and was significantly involved in the development of Chapter 17 of the Highway Capacity Manual 2000. He has been a sub-committee member of the Transportation Research Board (TRB) since 1995. He is a member of the Editorial Advisory Board of the Transportation Research Journal (Part A). He was the recipient of the 1997 Institute of Transportation Engineers (ITE) Young Consultant's Award. His research interests include signal system optimization, signal coordination, micro-simulation, and highway capacity analyses. He has authored and co-authored more than 20 peer reviewed journal and conference papers, covering a wide range of topics in the area of traffic engineering and operations.

COUNTERMEASURES FOR COMMERCIAL VEHICLE INCIDENTS DURING SEVERE WEATHER ON REMOTE INTERSTATE HIGHWAYS

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ABSTRACT

This paper describes the current state of practice on the use of countermeasures to reduce commercial vehicle incidents on remote interstate highways during severe weather. The FHWA reports that a CV crash costs between \$76,000 and \$117,000 with interstate highway closures due to these crashes causing millions of dollars loss to the region. The business practice of “just in time” delivery of goods and rolling warehouses requires that restrictions and closures of interstates be eliminated or kept to a minimum.

Nine western states were surveyed to document the types of countermeasures being used and the effectiveness of the countermeasure. The western states selected all had a major cross-country interstate traversing a mountain range. The locations of the selected segments were generally remote with mountainous terrain.

The researched countermeasures were grouped into the following categories: Decision-Making, Restrictions and Advisories, Traffic and Road Features, Information Systems, Surveillance and Detection and Automated Systems. Thirty-eight countermeasures were researched and thirteen countermeasures were recommended by the author. It was found that the all the states surveyed utilize a web site for up to date road and travel information. Automated systems were least used. Length restrictions and dynamic or changeable message signs were reported as the most effective tools to reduce CV incidents.

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INTRODUCTION

Heavy demands placed on existing interstate highways have made prevention or reduction of incidents that close the road or inhibit traffic operations a top goal of Departments of Transportation (DOTs). Incidents like commercial vehicle (CV) crashes typically create lane restrictions and interstate closures. These incidents require longer clearance time, that equates to more delay and exposure to secondary incidents. Hazardous material shipments, like nuclear waste, have increased and trends show both an increase in the number and length of these trips.

Weather has a profound effect on CV operators in the areas of mobility, safety, productivity, environmental quality, national security and DOT customer satisfaction. Extreme or severe weather conditions produce adverse effects on CV operations. Remote Interstates are significantly degraded when the roadway environment is subjected to extreme weather fluctuations. These interstate segments operate in an environment where free flow speeds and mobility are dictated hourly by weather. In western states, remote interstate segments typically cross over or around mountain ranges that can have volatile road surface and visibility conditions. These interstate segments are typically far from urban services and incidents are difficult to detect, verify and remove. The DOT struggle in these remote areas against Mother Nature by increasing surface maintenance, and utilizing passive and active information systems.

It was reported by the FHWA that 6,800 fatal crashes occur on roadways in adverse weather (1). Fatal rural crashes when compared to fatal urban crashes have a larger proportion of trucks involved (2). Sixty-seven percent of the fatal crashes involving large trucks occurred in rural areas during 2000 (3). Passenger car involvement in a collision with a large truck increases the probability of fatal injury to the driver of the passenger car by nine fold (4). This statistic is primarily due to the size and weight differences of the vehicles.

The FHWA also reports that the average per crash cost of a CV ranges between \$76,000 and \$117,000 (in 1999 dollars) (5). The total economic loss to the United States due to weather has not been reliably estimated, however, a one-day closure due to weather can cost tens of millions of dollars per region (6). The Wyoming Trucking Association reports that one-dollar is lost for every one minute of delay per CV (7). Other sources, such as the American Trucking Association, report a similar dollar value. The business practice of “just in time” delivery of goods requires that restrictions and closures of interstates be eliminated or kept to a minimum.

Emphasis by DOT has historically centered on weather related surface maintenance with recent improvements in traffic management and traveler information. Colorado and Arizona have completed Incident Management plans that include mountainous interstate corridors. These plans outline integrated systems that serve needs in maintenance, traffic management, and information.

This research paper documented current practices in use by Western DOT, their reported effectiveness for devices, and road features used to reduce CV incidents on remote interstates. Once all the road features and technologies are identified, a test case located in Wyoming will be performed. The study recommendations will be limited to incident reduction or prevention techniques as reported by DOT and findings in literature.

The primary reason for conducting this research was to document all existing road features and technologies particularly targeted towards reducing CV incidents. The Maintenance or Traffic Engineer would then have a documented source for reference. This information may aid in future decision making for upgrading or reconstruction projects. Also, the research may prove to be a source for technologies and road features to be considered once Nevada receives large amounts of nuclear waste shipments.

Research Objectives

The specific objectives of this research paper was to:

- Identify and document what countermeasures are being used by state DOT for reducing CV incidents on remote interstate highways;
- Determine obstacles or shortcomings of the countermeasures;
- Summarize the findings of all the road features and technologies found to be effective;
- Design a test case using the recommended technologies and road features; and
- Develop final recommendations.

Scope of Study

The scope of this study was to synthesize current Western State DOT practices for reducing and/or preventing commercial vehicle incidents on remote interstates during severe weather. The practices documented were technologies (typically electrical devices) and road features (chain area, etc.). In-vehicle warning systems and DOT surface maintenance practices are not covered in this research. Both items play a role in reducing CV incidents, however, only countermeasures dealing with engineering, not education or enforcement, was reported.

The focus of the research was on mountainous terrain found at high elevations (typically above 4,000 feet) in the western United States. These interstate segments are frequently hard hit by winter storms. They are plagued by route closures caused by surface and/or visibility conditions, and crash created lane blockage. In order to meet the objectives of this research, telephone interviews were conducted with thirteen maintenance and/or traffic professionals from nine different DOT. These professionals have expertise in traffic operations and incident management on remote interstate highways.

Organization of Report

The procedures used to develop countermeasures for CV incidents consisted of four primary tasks: literature review, data collection and analysis, recommendations, and application of the findings. These tasks are covered in detail in the following sections.

Literature Review

Examination of the current literature on transportation was performed in order to provide a list of countermeasures that can be applied to CV incidents. The selection of countermeasures was limited to items that the DOT can provide. Case studies and research were reviewed for any countermeasure that could be installed or used in remote locations. To keep the research as condensed as possible several countermeasures that appeared to have minimal potential were not considered in this research.

Data Collection

After the countermeasure list was pared down to a manageable and feasible number, a telephone survey was conducted with nine western DOTs. Contacts were made by telephone to record any relevant information that written surveys often do not get. It is hypothesized that frequently surveyed professionals with tremendous work loads will provide only necessary information when asked to record and send responses. The following questions were asked :

- Does your DOT have a problem with commercial vehicle incidents (typically crashes) on remote interstates during severe weather ?

- Which of the following items does your DOT utilize on or for remote interstates to reduce commercial vehicle incidents during severe weather? Rate each item with: 1 - not effective, 3-some what effective, 5-very effective.
- (A complete list of the 38 items is shown in Appendix A.)
- Does your DOT use any other countermeasures to reduce commercial vehicle crashes? Rate these items with the same scale as above.
- If your DOT uses dynamic or changeable message signs, are specific messages displayed for commercial vehicles?
- If your DOT uses Closed Circuit TV, is this given to the public or media?

Many of the professionals interviewed provided additional information such as what the DOT has planned for the corridor and why certain items were not effective. These additional items are included in the Department of Transportation Practices section of this report. A copy of the complete telephone survey is provided in Appendix A.

Recommendation Development

A set of tables was created to reflect the current practices and countermeasures reported to be effective. The effective countermeasures were based solely on the opinions of the maintenance or traffic professionals interviewed. Other factors such as; cost, department policies, site limitations, funding for operations and maintenance, and liability issues were not included and were beyond the scope of this report.

Application of Findings in a Test Case

The countermeasures found to be most effective were applied to a test segment of Interstate 80 that crosses through Eastern Wyoming. The design was based in part on recent studies done in Colorado and Wyoming (8,9). This approach yielded a comprehensive, integrated countermeasure design that may be employed by the DOT.

BACKGROUND

Traffic operations are generally defined as the road features and restrictions that shape the operating characteristics of the traffic stream. This can be thought of as pre-incident practices. Prevention of the primary or first incident is considered traffic operations. Incident Management, on the other hand, is post incident. An incident must take place in order to manage it. Both practices are interwoven.

The needs of the commercial operators and the environment typically associated with remote interstates are then defined. A brief discussion of selected countermeasures then follows.

Incident Management and Traffic Operations

Typically, incident management is a technique used to restore capacity to congested roadways in non-rural or urban locations as quickly as possible. These congested urban centers are found in most large cities. The existing roadway system breaks down due to peak demands and typically is a daily occurrence. The systematic application of effective incident management techniques has been well documented in congested urban centers. A one day shut down on a major interstate near large population centers could effect millions of people. The disrupted traffic would typically be routed to nearby alternate routes.

The rural and remote incident management applications are far less studied. They are not systematically applied, predictable or detectable, and are not a daily occurrence. This disparity is due in part to the demographics of the population centers in America. In rural and remote locations, fewer than one-

hundred thousand people are effected when interstate routes are closed for a day. Alternate routes may not exist. When less people are effected, less attention and money are given to the problem. A good example would be the release of wolves in sparsely populated areas versus releasing them in Central Park.

The prevention of a primary incident for the purpose of this study, is considered traffic operations. The traffic related countermeasures reviewed generally fit into items defined by the Manual on Uniform Traffic Control Devices (10) and Items defined by American Association of State Highway Transportation Officials (AASHTO) “A Policy on Geometric Design of Highways and Streets.” (11)

Incident Management generally consists of seven stages (12), listed below.

- Detection
- Verification
- Motorist Information
- Response
- Site Management
- Traffic Management
- Clearance

This research only covered detection, verification, motorist information and traffic management stages. The other stages are necessary to incident management practices but are not included in order to keep the report condensed. Response, site management and clearance stages involve emergency services which are important to safely and quickly clear an incident.

Commercial Vehicle

Large trucks are defined as commercial vehicles that weigh over 10,000 pounds. The majority of commercial vehicles identified most likely to benefit from this research are long haul, cross country, interstate trucks. Long haul trucks customarily start and end at large industrial or commercial centers, such as sea ports, or where large production manufacturing centers exist. Long haul truck drivers may have limited knowledge of the different roadway environments they will have to navigate.

Roadway Environment

Remote interstate routes researched for this report collectively carry over 35,000 long haul trucks per day. They supply and ship goods from the eastern and central part of United States to the west coast. NAFTA trucking from Canada to Mexico is also prevalent. Five interstate routes cross over western United States from east to west. Four interstates must traverse remote segments that pass over or near mountain ranges such as the Rocky Mountains. Terrain in the remote areas typically include steeper than normal grades with physical limitations to the median separations and through lane additions. Most of the interstates are four lane roads without near by alternate routes.

The countermeasures found in research were broken into six main categories. These main categories were selected in order to keep the countermeasures grouped together for side by side comparisons. What follows is a discussion of the category, and a list of each countermeasure along with some descriptions of lesser used or known countermeasures. Some of the more common countermeasures do not have a description.

Decision-Making

The decision-making category contains two practices. Documented plans put in place to manage or prevent incidents and computer-decided plans based on actual events taking place. The latter is totally dependent on real time data collected from the remote site. The two practices to be researched are :

- Documented corridor incident management plans
- Computer-aided dispatch

Corridor specific incident management plans are unique plans designed for particular segments of road that typically have operational breakdowns. An example of a thorough mountain corridor plan was done by the Colorado Department of Transportation for Interstate highway 70 ([8](#)).

Computer-aided dispatch entails software that collects real time weather, road conditions and traffic data. The software detects operational or maintenance problems and advises dispatchers of predetermined scenarios to execute. This countermeasure is typically used in traffic operations centers.

Restrictions and Advisories

This category is influenced by state statutes or physical roadway constraints. Maximum speed limits set for a rural interstate are typically defined in state statutes, but engineering studies can be done to alter these limits. Typically, the maximum speed is reduced due to the design of the road or the condition of the road surface or the operating speed of the traffic. The speed limit in some states are set lower at night for all vehicles. Truck speed limits set lower than the maximum speed limit is also reported. These variations of the maximum speed limit have the potential to create greater speed differences amongst the trucks and passenger cars. This speed differential may offset the safety gains intended by the restriction.

Variable speed limits utilize traffic speed and volume detection, weather information, and road surface condition technology to determine appropriate speeds at which drivers should be traveling, given current roadway and traffic conditions ([13](#)). To date only a few states have tried the use of variable speed limits on remote interstates. Figure 1 shows an experimental variable speed limit sign. Automatic selection of the speed limit has run into data collection device failures.

Restrictions can also influence the height, weight, and width of vehicles allowed on the road. These restrictions are typically done for triple trailers on a permanent or seasonal basis and for temporary measures during severe weather.

Chain restrictions are common during severe weather on mountain roads. This restriction requires all trucks and some cars to have chains installed prior to reaching a certain point on the highway.

It should be noted that a restriction of any kind is only as good as the enforcement and fines associated with it. A good example of non-compliance to restrictions on rural interstates is the maximum speed limit. In Wyoming, the mean rural interstate speed is approximately the speed limit, 75 miles per hour. This would mean that about half of the motorists are exceeding the posted speed limit and are not in compliance.

Advisories as discussed in this report are warnings to specific vehicles concerning hazards. States post advisory speeds due to road conditions and also advise no empty or light truck loads during severe wind conditions.

The practices concerning restrictions and advisories researched are listed below.

- Reduced Winter Speed Limits
- Variable Speed Limits
- Reduced Truck Speed Limits
- Advisory Speeds for Trucks
- Lane Restrictions for Trucks
- Closures to Trucks only
- Length Restrictions

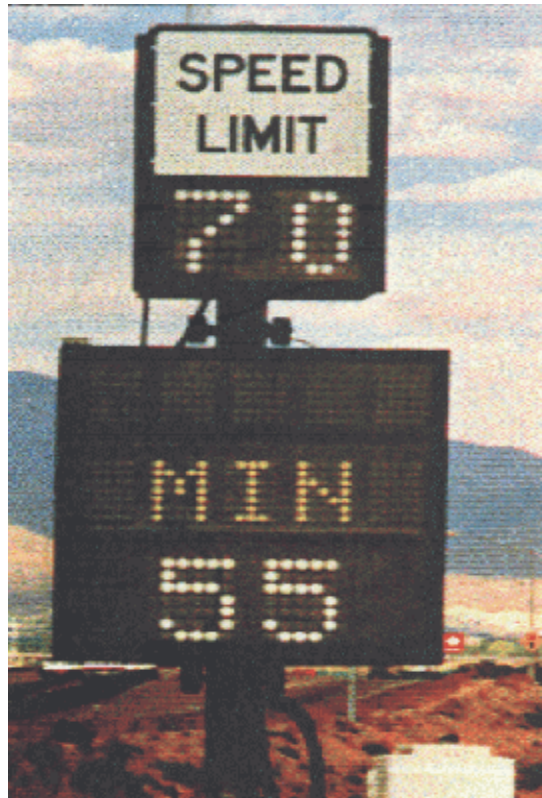


Figure 1. Variable Speed Limit Sign

Traffic and Road Features

Traffic and road features are the items defined by AASHTO's "A Policy on Geometric Design of Highways and Streets" (*11*) and the Manual of Uniform Traffic Control Devices (MUTCD) (*10*). The references are mandated by the Federal Highway Administration (FHWA) to be used when constructing or modifying the interstate system. States do have the right to adopt other policies or manuals but, they differ only slightly from the aforementioned.

Countermeasures in this category are used to improve traffic operations and thus reduce incidents or crashes. This prevention or hazard elimination practice is where the highway dollars have historically been spent. The practices found in research include:

- Truck climbing lanes
- Chain-up areas
- Signed truck parking areas
- Edge line rumble strips
- Additional delineation
- Mile Marker spacing
- Snow fence
- Median turn around
- Pavement marking changes
- Additional or larger warning signs
- BRIDGES MAY BE ICY signs
- Manual road closure gates

Snow Fences control blowing snow. This countermeasure can prevent snow drifts on roads, decrease snow removal costs, increase driver visibility, and reduce slush and ice formation. Snow fences work by collecting snow in drifts before it reaches the highway. This improves visibility by reducing the concentration of snow in the air (14). Higher wind gust speed tends to result in more injurious crashes, whereas higher snowfall intensity tends to result in less injurious crashes (15). Snow fences should be considered where ground blizzards create road closures and/or crashes. Figure 2 shows the dramatic results that snow fence can achieve.

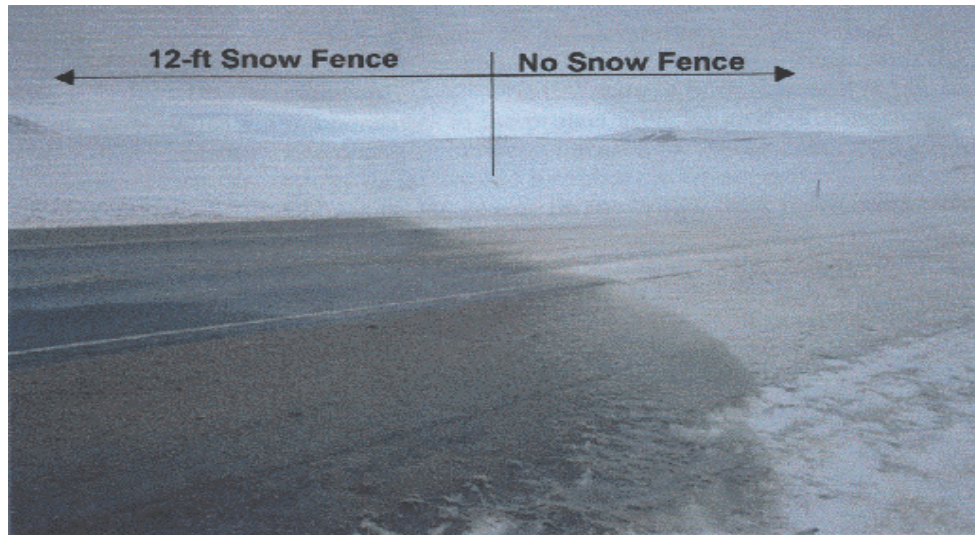


Figure 2. Snow Fence Results

Manual road closure gates are necessary when courts or enforcement require physical barriers across roads in order for the road to be closed. An adaption to the railroad gate is taking hold across Northern and Western states. The Wyoming road closure gate shown in Figure 3 provides a physical barrier. This gate requires advance warning devices to warn motorists of the closure. Note that on ramps must also be gated to prevent motorists from entering the interstate. Interchanges should be used to close interstates due to several safety and operational factors. Interchanges are decision points that drivers are familiar with and truck movements are accommodated at interchanges. Median turn arounds should be avoided for fixed road closure points. Turning traffic at grade on the main line of the interstate violates driver expectancy. Merging vehicles into potential live lanes can also be dangerous.

Information Systems

Information systems disseminate road and weather conditions as well as restrictions to the motorist. These systems include the following:

- Dynamic or changeable message signs (DMS/CMS)
- Signs with Flashing Beacons
- Highway Advisory Radio (HAR)
- Internet Web sites
- Commercial radio and television broadcasts
- 511 or toll free phone numbers



Dynamic or changeable message signs can be used to provide timely, accurate information in advance of, and at the scene of an incident. Large trucks can significantly limit the distance at which message signs can be read (*16*). Overhead mounting of the sign should be considered for high truck volume roads. Figure 4 is a picture of a cantilever overhead mounted dynamic message sign. This type of mounting is ideal for rural areas because of the decreased need for guardrail in the median.



Figure 4. Cantilever Overhead Mounted Dynamic Message Sign

Signs with red or yellow flashing beacons have been used to warn drivers of hazards or speed limit changes. Beacons that can be activated remotely provide timely information about road closures, chain laws, and highway advisory radio broadcasts. Figure 5 shows a sign that would be suitable for remote activation of flashing beacons.



Figure 5. Sign with Flashing Beacons

Highway advisory broadcast messages must be accurate, timely and useful. Advance signs with flashing beacons should be placed approximately one mile prior to the outer edge of the radio broadcast range (17). Advance signing is intended to inform motorists as they approach an HAR broadcast area. This signing would allow ample time for the motorists to tune to the station and hear the message. Weather, road conditions and restrictions are information relayed to trucks by HAR systems.

Information systems are constantly being enhanced to provide motorists with information regionally, locally and site specific. Regional coalitions of adjoining DOT on Interstates 80 and 90. These coalitions appear to have the potential to provide uniform consistent messages to the trucks, from state to state. The main goal is to provide advanced information well in advance of problems areas and closures. Keeping the drivers confidence in information systems is key in reaching their desired effectiveness.

Surveillance and Detection

The ability to detect and verify, incidents, road conditions or driver visibility is the weakness of today's technology when used in the remote environment. The vast area needed for coverage may require a satellite view of the highway. Typically, the coverage needed exceeds twenty miles of road surface. Today's deployed technology in remote areas are point or spot detectors or cameras that can easily miss a small storm or crash just over a hill.

Some remote interstate segments do not have adequate coverage for communication back to a traffic or maintenance center. Cellular phone coverage does not exist in some of these segments. Rural cellular service covers 90 percent of the population and only 70 percent of the US land mass (18).

The surveillance and detection practices found were:

- Closed circuit television (CCTV)
- Web Cameras
- Count/speed/classification sites for monitoring

- Call boxes
- Weather stations (RWIS)

CCTV has been used in urban areas to assess incidents in order to provide proper response. Video cameras mounted along the remote interstate would provide detection, verification or improved response and site management. Due to the high cost of a camera capable of operation in a harsh environment and the cost of live video images back to a control center, the use has been limited in remote areas. In remote areas lighting was found to be a necessity for twenty-four hour a day surveillance.

Call boxes are dedicated emergency phones located along the highway to allow stranded motorists access to assistance. These phones can also be used to report incidents. Location and placement can be a problem in remote locations.

Weather Stations or Road Weather Information systems (RWIS) provides remote detection of:

- Atmospheric, road surface, and subsurface temperature
- Relative humidity
- Wind speed and direction
- Precipitation
- Chemicals on the road

When this information is transmitted to an operation center it enables timely road surface maintenance. Most DOT are providing this information on their web sites.

Automated Systems

Automated systems are relatively recent changes being introduced to highways. Some of these systems have the potential to specifically target problem areas or individual vehicles in danger. The systems found were:

- Ice detection warning systems
- Automated bridge de-icers and anti-icers
- Dynamic curve warning systems
- Automated road closure systems

Ice detection systems sense pavement surface conditions and warn motorists of the hazard they will soon encounter. Bridge de-icers are typically installed on bridge decks and can automatically spray chemicals on the deck to prevent ice from forming. Caution should be used with any automated bridge de-icer or anti-icer in locations that are susceptible to blowing snow (*19*). The chemical acts to catch the moving snow thus creating a slush condition which may be more harmful.

The only research found on curve warning systems pertained to two lane roadways. However, research was found on a down hill truck speed warning system. This evaluation was on a system installed on I-70 in Colorado and showed a significant reduction in truck speeds. Speed detection loops and weigh and motion were used in conjunction with a variable message sign to warn truck drivers when speed and weight thresholds were reached. The authors noted specific weight ranges with associated advisory speeds (*19*). For instance, a 90,000 pound truck would be given a lower advisory speed than a 20,000 pound truck.

Automated road closure systems have been used in urban areas to allow alternating traffic on one-way HOV lanes. These systems are not crash worthy and require barrier protection. The Wyoming gate shown in Figure 5 has been approved by the FHWA and is crash worthy. Two companies have documented successful infield tests of automated road closure systems using the automated gate. South

Dakota and Minnesota Departments of Transportation concluded that this gate design could be used for automation due to simplicity and crash worthiness (21, 22). Automated closure gate systems when used on the main line of the interstate may require intensive advanced motorists information and possibly real time video surveillance. The potential to open and close roads in a more timely manner will greatly aid in the reduction of secondary crashes and reduce the need for man power that was used to accomplish manual closures.

Automated detouring/trail blazing is used to redirect motorists to alternate routes when the primary route is closed. These systems use blank-out signs and symbols or dynamic message signs for motorist information.

DEPARTMENT OF TRANSPORTATION PRACTICES

States Selected for Survey

Ten interstate roadway segments located in nine western states were selected for use in the survey. All nine states have interstates that carry a large portion of the cross country long-haul trucking. An internet search of web sites for: Arizona, Colorado, New Mexico, Montana, Idaho, Nevada, Utah, Washington and Wyoming was used to screen for remote interstate roadways. District or regional employees in the maintenance or traffic fields were selected to be surveyed. This was done to insure employees with actual knowledge of the interstate segment were chosen. The selection was done by reviewing staffing and their responsibilities taken from respective DOT web sites and/or from personal knowledge of individuals. A mix of maintenance and traffic backgrounds was necessary to provide differing viewpoints on the deployed countermeasures. Table 1 indicates some facts concerning the segments selected for survey. Figure 6 shows the approximate location of the segments.

Table 1. Interstate Segments Used in Survey (Ref. 23-32)

State	Route	Location	AADT/CAADT	Speed limit
Arizona	I-40	Ashfork - Twin Arrows	17,000/5,950	75
Colorado	I-70	Hanging Lake Tunnels	13,000/1,690 (est.)	65-75
Colorado	I-70	Vail Pass	27,000/3,510	65-75
Idaho	I-90	Lookout Pass	6,100/1,900	55
Montana	I-90	Lookout Pass	5,985/1,999	65-75
Montana	I-15	Monida Pass	2,501/810	65-75
Nevada	I-80	Pequops Pass	10,000/2,877 (est.)	75
New Mexico	I-25	Raton Pass	10,000/1,700 (est.)	65-75
Utah	I-80	Silver Creek Canyon	28,000/5,320	75
Utah	I-80	Utah State line - Salt Lake	13-40,000/5,320 (est.)	75
Washington	I-90	Snoqualmie Pass	25,678/4,622	55-65
Wyoming	I-80	Pole Mountain	11,000/5,000	75
Wyoming	I-80	Elk Mountain	10,000/5,950	75

*AADT- Average Annual Daily Traffic, CAADT - Commercial Average Annual Daily Traffic



Figure 6. Interstate Segments used for survey

Decision-Making Practices

Table 2 lists the two countermeasures surveyed in the Decision-Making category. The survey showed that both countermeasures were rated higher than some what effective. Only two states indicated that a documented corridor specific incident management plan did not exist.

Table 2. Reported Practices

Countermeasure	Average Reported Effectiveness Scale 1-5	Number of States Using the Countermeasure
Computer-Aided Dispatch	4	2
Corridor Incident Management Plan	3.3	7

Only two respondents from two different states reported that they were using computer aided dispatch. The average effectiveness rating of 4 was in between some what effective and very effective. One comment was made “traffic operation center uses this.”

Nine of the thirteen respondents stated that a Corridor Incident Management Plan was in place. The average effectiveness rating of 3.3 was slightly higher than somewhat effective. Comments included; “too much turnover in personnel”, “if used the plan will work”, “excellent resource for road furniture improvements and upgrades”, “just starting with the plan”, “public relations dream”, “use a more informal plan”, “ hard to use when the heat of the battle is on.”

Restrictions and Advisories Practices

Table 3 lists the seven countermeasures surveyed in the restrictions and advisory category. The survey showed that length restrictions were used by the majority of the states and appears to be very effective.

Table 3. Reported Practices

Countermeasures	Average Reported Effectiveness Scale 1-5	Number of States Using the Countermeasure
Reduced Winter Speed Limits	5	1
Variable Speed Limits	5	1
Length Restrictions	4.8	7
Reduced Truck Speed Limits	4	4
Advisory Speeds for Trucks	4	4
Closures to Trucks only	3.4	4
Lane Restrictions for Trucks	2.8	4

One respondent and one state reported using winter reduced speed limits. The effectiveness was rated as very effective. Comments included; “ would love to use them”, “plan on using in the future”, “steep grades may some day require the use”, “ any maximum speed set may not be a safe speed.”

One respondent and one state reported using variable speed limits. The effectiveness was rated as very effective. Comments included; “ winter causes large speed variations”, “manually set and are an enforcement problem.” No objective data was asked for or cited. The effective rating was opinion based.

Length restrictions were reported in use by nine respondents from seven different states. The average effectiveness of 4.8 was reported as slightly under very effective. All comments concerned restricting triple trailers by season, event, route and by statute.

Reduced truck speed limits was reported in use by four respondents from four different states. The average effectiveness of 4 was in between some what effective and very effective. One comments was, “used statewide.” No objective data was asked for or cited. The effective rating was opinion based.

Advisory speeds for trucks was reported in use by four respondents from four different states. The average effectiveness of 4 was in between some what effective and very effective. One comment was, “used on severe downgrades.”

Five respondents from four different states reported using interstate closures to trucks and open to other vehicles. The average effectiveness of 3.4 was above somewhat effective. Comments included; “worked well during the Olympics”, “used for high profiles and chain law”, “sorting vehicles at the closure point is a real problem”, “used during high winds.”

Five respondents from four different states reported using lane restrictions for trucks. The average effectiveness of 2.8 was slightly below somewhat effective. Comments included; “used on climbing lanes”, “not effective, not enforced during storms”, “restricted to the far right lane on down hill grades”, “left lane minimum speed of 55 mph is poor”, “restrictions to left lane for snow removal.”

Traffic and Road Features Practices

Table 4 shows the twelve countermeasures surveyed in the traffic and road features category. The top five countermeasures are being used by the majority of DOTs surveyed. Visibility and traction during storms appear to be the primary concern.

Table 4. Reported Practices

Countermeasure	Average Reported Effectiveness Scale 1-5	Number of States Using the Countermeasure
Snow Fence	4.3	5
Additional Delineation	4.2	7
Chain-up Areas	4.2	6
Edge Line Rumble Strips	4.1	7
Manual Road Closure Gates	4	6
Pavement Marking Changes	4	2
Median Turn Around	3.8	8
Truck Climbing Lanes	3.5	6
Additional or Larger Warning Signs	3.4	8
Mile Marker Spacing	3	1
Signed Truck Parking Areas	2.8	4
Bridges May Be Icy Signs	2.3	7

Snow fence was reported in use by six of the respondents from five states. The average reported effectiveness of 4.3 was above half way between slightly effective and very effective. Comments included; “no room for snow fence”, “no blowing snow problems.”

Additional delineation was reported in use by eleven of the thirteen respondents from seven different states. The average reported effectiveness of 4.2 was reported half way between slightly effective and very effective. Comments included; “taller delineators are needed due to snow depth”, “white out conditions dictate reducing the spacing.” Most states reported using snow poles or taller posts. One state noted that normal spacing is halved with a reflective dipped background on the post doubling the crystals. This same state noted that guardrail and bridge rail were delineated as well.

Chain-up areas were reported in use by nine respondents from six different states. The average effectiveness of 4.2 was reported as in between some what effective and very effective. Comments included; “the areas become plugged with parked trucks”, “the areas were not designed to handle the volume of trucks”, “a thirty minute parking restriction was needed”, “advance signing is important.”

Edge line rumble strips were reported in use by eleven of the thirteen respondents from seven different states. The average reported effectiveness of 4.1 was reported half way between slightly effective and very effective. Comments included; “considering their use”, “blade wear on plows is concern”, “used during white outs to feel where the road is”, “trucks line up on them during severe weather”, “may not work well with ice and snow in them”, “used heavily during poor visibility.”

Manual road closure gates were reported in use by eight respondents from six different states. The average effectiveness of 4 was reported as half way between slightly effective and very effective. Comments included; “Traffic still goes around the gates”, “in process of installing these devices”, “only ramps are allowed to be gated.” This response was noted three times.

Pavement marking changes were reported in use by two respondents from two different states. The average reported effectiveness of 4 was reported half way between slightly effective and very effective. Comments included; “6 inch edge lines were used”, “markings do not last on the this section of road.”

Median turn arounds were reported in use by ten of the respondents from eight different states. The average reported effectiveness of 3.8 was below half way between slightly effective and very effective. Comments from all but two indicated that these turn arounds were used only by maintenance and emergency providers. Several states indicated that these turn arounds were dangerous but necessary.

Truck climbing lanes or third lanes were reported in use by seven respondents in six different states. The average effectiveness of 3.5 was reported as slightly higher than somewhat effective. Comments included; “trucks plug the third lane as well when the road surface is poor and enforcement is impossible during poor conditions”, “coming soon”, “need more but the protected forest is in the way”, “will not use any more due to lack of enforcement.”

Additional or larger warning signs were reported in use by nine respondents from eight different states. The average effectiveness of 3.4 was reported as slightly higher than some what effective. Comments included; “overhead mounting works best with the high truck volumes”, “adding flashing beacons appears to get attention”, “doubling up on the signs”, “grade warning signs are 8'x10' and spaced every two miles.”

Mile marker spacing of less than one mile was used by two respondents both from one state. The average effectiveness of 3 was reported as slightly effective. Comments included; “helpful during multiple wrecks”, “use in certain areas only”, “½ mile spacing used in high crash areas.”

Signed truck parking areas were reported in use by five respondents from four different states. The average reported effectiveness of 2.8 was just below slightly effective. Comments included; “the parking areas are too small”, “plowing these areas is tough”, “ these areas become pig pens”, “brake and load check areas are also signed”, “chain off stations should be used”, “rest areas and truck stops are relied on.”

BRIDGES MAY BE ICY signs were reported in use by eleven respondents from seven different states. The average effectiveness of 2.3 was reported below some what effective. Comments included; “static signs that are abundant do not keep the drivers attention”, “a lawsuit forced removal”, “overused.”

Information Systems Practices

Table 5 shows the seven countermeasures surveyed in the information systems category. The top two countermeasures were changeable message signs. The primary concern was to give the truck driver various messages concerning the road ahead. This category had the most countermeasures being used by DOTs. Restrictions, warnings and advisories appear to be the primary message given to truck drivers. All surveyed states utilize a web site for dissemination of current and in some cases real time information.

Table 5. Reported Practices

Countermeasure	Average Reported Effectiveness Scale 1-5	Number of States Using the Countermeasure
Changeable Message Signs at Diversion Points	4.7	6
Changeable Message Signs Near Problem Areas	4.5	6
Signs With Flashing Beacons	4.3	6
Web Site with Road, Weather and Restrictions	4	9
Highway Advisory Radio - HAR	3.9	8
511 or Toll Free Number for Road Conditions	3.4	7
Kiosks in Weigh Stations, Rest Areas or Truck Stops	3.4	3

Dynamic or changeable message signs at diversion points well in advance of problem areas was reported in use by nine respondents from six different states. The average reported effectiveness of 4.7 was just below very effective. Comments included; “planned for installation”, “ message is only good for the first ten minutes.”

Dynamic or changeable message signs in problem areas was reported in use by eight respondents from six different states. The average reported effectiveness of 4.5 was just below very effective. Comments included; “best information device to install”, “planned for installation”, “radio communication to the sign is faulty”, “ message is only good for the first ten minutes.”

Changeable messages used specifically for trucks were reported as; CHAIN LAW FOR TRUCKS, HIGH WIND WARNING ADVISE NO EMPTY OR LIGHT TRUCKS, TRUCK SPEED LIMIT 50 MPH, VEHICLES OVER 30,000 GVW RESTRICTED TO RIGHT LANE, ADVISORY FOR TRUCKS DO

YOU HAVE CHAINS?, LOAD RESTRICTIONS NO HAZMAT, REDUCED SPEEDS FOR DOUBLES, HIGH PROFILE WIND ADVISORY.

Static signs with flashing beacons were reported in use by nine respondents from six different states. The average reported effectiveness of 4.3 was below very effective. Comments included; “the beacons are automated.” Messages included; TUNE TO..., CHAIN LAW, ROAD CLOSED, ROAD CLOSED AHEAD, all with the message WHEN FLASHING. Blank out type signs were mentioned by two states.

A website with road, weather and restrictions was reported in use by all thirteen respondents from nine different states. The average reported effectiveness of 4 was half way between slightly effective and very effective. Comments included; “8 million hits were recorded during one month this past winter”, “truck dispatchers and radio stations monitor the site during storms.”

Highway Advisory Radio was reported in use by eleven respondents from eight different states. The average reported effectiveness of 3.9 was half way between some what effective and very effective. Comments included; “old AM system is poor quality in the mountains”, “switching to a FM system”, “truckers do listen to HAR”, “many complaints with AM system, too noisy, poor reception”, “looking into installing”, “being used 25 miles in advance of pass”, “works well for closure information.”

The 511 or toll free number for road conditions was reported in use by ten respondents from seven different states. The average reported effectiveness of 3.4 was just above some what effective. Comments included; “switching to 511”, “snow hotline works well”, “800 number is awkward to negotiate, slow to use and not user friendly.” Six states use toll free numbers and one state uses 511. Two states are planning to install a number.

Kiosks in weigh stations, rest areas or truck stops were reported in use by three respondents from three different states. The average reported effectiveness of 3.4 was above somewhat effective. Comments included; “too early to tell effectiveness”, “installed at port of entry”, “will install at a rest area very soon”, “removed by business council due to cost.” Two states are planning to install kiosks. No states reported kiosks in truck stops.

Surveillance and Detection Practices

Table 6 shows the five countermeasures surveyed in the surveillance and detection category. The top two countermeasures were CCTV and web cameras. The primary concern was to verify road and visibility conditions. Most of the states reported using RWIS or weather stations. The web camera phenomenon has very little value to maintenance personnel and may be a public relations front. The author believes that the tourist industry should assume this role. A search of several DOT’s web sites found outdated (stale) pictures or photos that had no value to motorists. The high effective rating in this survey of web cameras had to be attributed to positive customer feedback.

Closed circuit television was reported in use by six respondents from four different states. The average reported effectiveness of 4.5 was just under very effective. Comments included; “used in tunnel areas for break downs”, “the system will be expanded”, “fiberoptic cable used”, “live and still shots are sent to the website”, “lighting is critical”, “type of camera is important.” Only one state does not give the video feed to the public or media.

The use of web cameras was reported by seven respondents from six different states. The average reported effectiveness of 4.3 was under very effective. Comments included; “15 minute lag time is too slow for maintenance or surveillance use”, “no lights was a mistake”, “picture quality is poor”, “downtime is a problem”, “instead of potholes people complain about wanting more pictures”, “feel good for the public only.”

Table 6. Reported Practices

Countermeasure	Average Reported Effectiveness Scale 1-5	Number of States Using the Countermeasure
Closed Circuit Television	4.5	4
Web Cameras	4.3	6
Weather Stations - RWIS	4	8
Traffic Monitoring Sites	3.7	4
Call Boxes	3	2

Weather stations - RWIS, were reported in use by twelve respondents from eight different states. The average reported effectiveness of 4 was half way between slightly effective and very effective. Comments included; “valuable information for maintenance and posted on web site”, “communication to the site is a problem”, “due to early failures, some maintenance personnel lost confidence.”

Traffic monitoring sites were reported in use by four respondents from three different states. The average reported effectiveness of 3.7 was above some what effective. Comments included; “used in tunnel areas”, “not monitored regularly.”

Call boxes were reported in use by three respondents from two different states. The average reported effectiveness of 3 was some what effective. Comments included; “used at interchanges only”, “coming soon to rest areas that do not have phone service”, “nobody uses, would like to get rid of them”, “maintenance problem due to vandalism.”

Automated Systems Practices

Table 7 shows the five countermeasures used in the automated systems category. These systems are relatively new and are not in wide spread use on the locations surveyed. These systems have the potential to become an effective countermeasure for some site specific problems.

Table 7. Reported Practices

Countermeasure	Average Reported Effectiveness Scale 1-5	Number of States Using the Countermeasure
Automated Road Closure Systems	5	1
Automated Detouring Systems	5	1
Ice Detection Warning System	4	2
Automated Bridge De-Icers	1 and 5	1
Dynamic Curve Warning Systems	Not Used	None

One automated road closure system was reported. The reported effectiveness of 5 was very effective. Comments included; “the system detects avalanches and closes gates automatically”, “incident response time and secondary crashes could be reduced if a good system was available.”

One automated detouring system was reported. The reported effectiveness of 5 was very effective. Comments included; “the system uses portable dynamic message signs.”

Ice detection warning systems, were reported in use by two respondents from two different states. The average reported effectiveness of 4 was half way between slightly effective and very effective. Both systems need confirmation by a dispatcher prior to warning system activation. Comments included; “reliability and down time is a problem”, “automation may happen soon.”

Automated bridge de-icers or anti-icers were reported in use by one respondent. The reported effectiveness of 5 was very effective. Comments included; “down time is real problem, the system is very effective when it works”, “several of the maintenance foreman have a need for them.”

No respondents are currently using dynamic curve warning systems. The use of these systems is under evaluation on several two lane roads throughout the west. One state reported that they use a slow moving vehicle detector which warns high speed vehicles of slow moving trucks around a curve. The automated speed detection system for trucks on downhill grades utilized on I-70 is very similar in operation to the dynamic curve warning systems.

Additional Countermeasures

The survey respondents were asked to provide any additional countermeasures the survey did not cover. Additional countermeasures reported in use were:

- Flashing beacons on speed limit signs
- Pusher truckers to clear stalls, spin-outs and minor crashes
- Message sequencing of chain law well in advance of chain areas
- Linear delineator system attached to median barrier
- 24 hour shifts seven days a week provide eyes and ears of the road condition
- Truck escape ramps
- Fold up signs
- LED ICY road signs and blank out signs for chain law
- Overhead mounted truck warning signs for grade and curves
- Reenforced median barrier or Texas barrier
- GPS tracking on the maintenance fleet
- Hazmat Restrictions through sensitive areas
- Glare screen on median barrier
- GasEx avalanche control and an avalanche team
- Mass fax and email when incidents occur

RECOMMENDED COUNTERMEASURES

Countermeasures for large truck incidents during severe weather selected for use on remote interstate segments must be effective and beyond the experimental or trial stages. The criteria used to short list countermeasures recommended for consideration must have an effective rating of at least 3.9 and four states reporting the use. The rating of 3.9 indicates the countermeasure was reported has effective. If four states reported using the countermeasure that countermeasure is more than likely beyond a trial or experimental stage.

The countermeasures meeting this criteria are: reduced truck speed limits, advisory speeds for trucks, length restrictions, chain up areas, edge line rumble strips, additional delineation, snow fence, manual road close gates, changeable message signs at problem areas and diversion points, static signs with flashing beacons, highway advisory radio, closed circuit television, web cameras and weather stations. Fourteen of the thirty-eight items surveyed are recommended for installation on remote interstates.

Implementation of these countermeasures should follow the suggested procedures:

1. Screen and plot crash data to find problem areas
2. Inventory all existing traffic control devices and road features
3. Conduct a safety and traffic operations study to determine best countermeasures and placement
4. Check corridor for consistent and uniform countermeasure applications
5. Budget for operations and maintenance

APPLICATION OF RESEARCH FINDINGS

Design of Countermeasures for Interstate 80 in Eastern Wyoming

Utilizing the fourteen countermeasures recommended in this report, a system was developed for a segment of Interstate highway 80 in eastern Wyoming. This segment of road traverses the highest point along interstate 80 from coast to coast. The road goes over a small mountain range that lies between the city of Cheyenne and the town of Laramie. A map of the segment is shown in Figure 7. This segment of highway has very limited services and is considered remote.

The weather for this area can be extreme during the winter months. High winds creating blowing and drifting snow plague this part of Wyoming. Traffic volumes on this four-lane interstate average 11,000 vehicles per day including 5,000 large trucks. The majority of the trucks are long haul trips starting several hundreds of miles away.

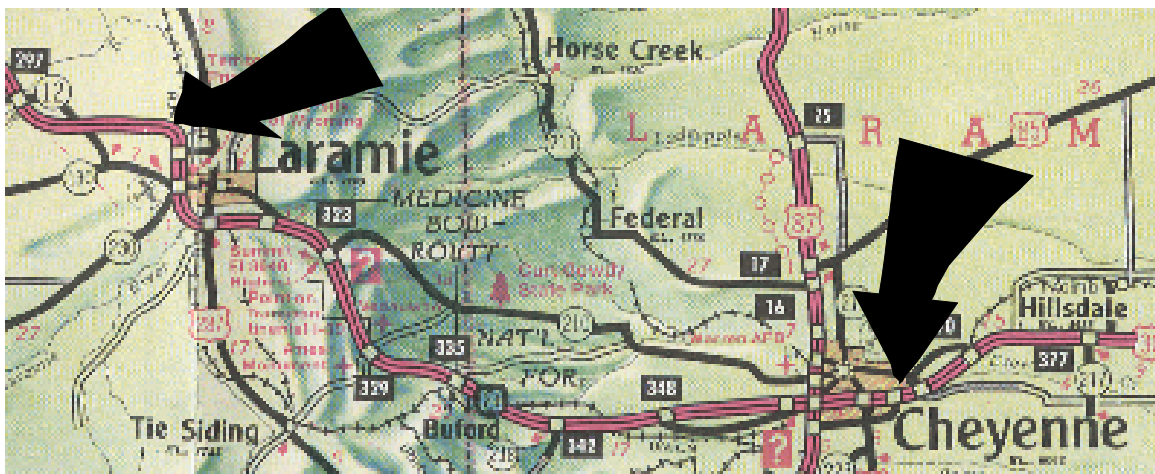


Figure 7. Test Cast on Interstate Highway 80

The first procedure in the design process was to screen the entire Interstate 80 through Wyoming to find the highest crash rate segments. The Cheyenne to Laramie segment showed crash rates two to four times the statewide average interstate crash rate. This segment was also closed more often than other parts of Interstate 80. Over the last four years this segment was closed forty times for a total elapsed time of thirteen days. The average closure time is about eight hours and the longest closure was thirty-eight hours.

A safety improvement study completed in June 2002 revealed the crash problems for this segment of interstate highway (9). The scope of this study did not include investigation of the type of vehicles involved in the crash. The crash data shown in Figure 8 compare commercial vehicle crashes to other vehicle types. The crashes shown occurred during winter conditions over a six-year time span.

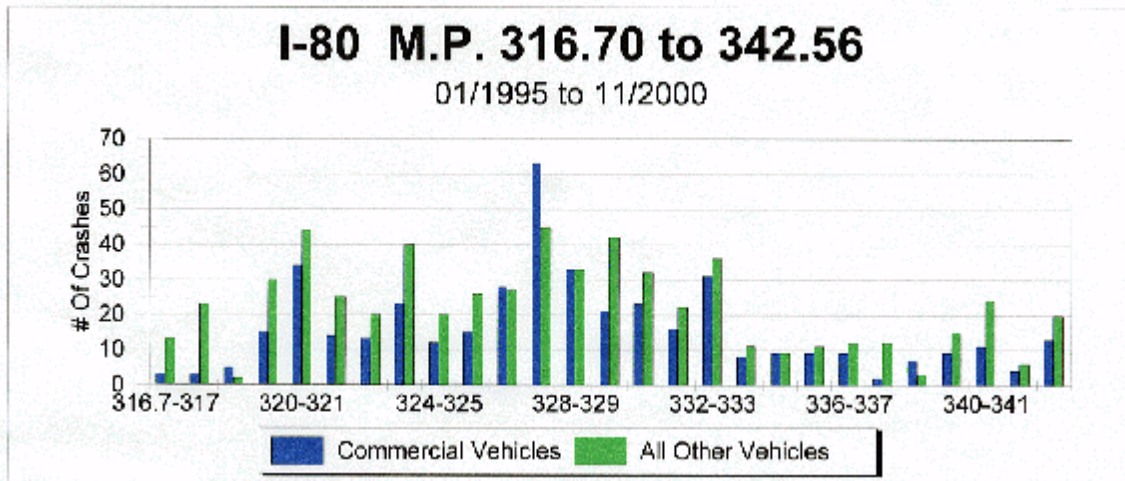


Figure 8. Crashes on Interstate 80 During Winter Conditions

Winter condition incidents make up nearly eighty percent of the total number of crashes that occur on this segment. The higher crash areas for commercial vehicles appear to be similar to that of other vehicles. The spike of CV crashes around milepost 328 and the number of CV crashes between mileposts 320 and 333 are two items that stand out.

Commercial vehicle crash rates were computed using CV crashes to million commercial vehicle miles of travel. The rates at locations on the test case segment were found to be two to four times higher than the statewide crash rate. Injuries were analyzed and found to be over represented between mile post 320 to 333.

The second and third procedure was partly taken from the safety study mentioned above. The study presents the best countermeasures and placement based on well documented roadway and environmental conditions. The countermeasures proposed for use on this highway by Tabler (11) included eight of the fourteen countermeasures recommended in this research. Additional countermeasures were proposed in the study by Tabler (11), however, these details were beyond the scope of the test case and not presented. Tables 8 and 9 show the locations where the recommended countermeasures should be installed and gives the primary use.

Table 8. Recommended Countermeasures - West Bound

Countermeasure West Bound	Location Approximate Milepost	Primary Use
CMS	East of Cheyenne 364	Advance information for conditions and route diversion
FBS	364, 362, 359, 358	Tune to.....when flashing
HAR	High point good coverage	Road, weather, closures
FBS	358	Road closure when flashing
CMS	357	Road conditions and closure
Manual road closed gate	357	Physical barrier for closure
FBS	On ramps of 3 interchanges 348, 345, 342	Warn drivers before getting on 80 that it is closed
FBS	Good tangent section 341	Winter condition warning when flashing
FBS	On ramps of Remount interchange 339	Warn drivers before getting on 80 that it is closed
CMS	East of Buford Interchange 335	Incident management Turn around at interchange
FBS	On ramp of Buford Interchange 335	Warn drivers before getting on 80 that it is closed
FBS	335	Tune to.....when flashing
HAR	High point good coverage	road, weather, closures
Chain up area	332	Separated pull off
CMS	334	Advisory speeds, Visibility, Road conditions
CMS	331	Advisory speeds, Visibility, Road conditions
FBS	On ramp of Vedauwoo Interchange 329	Warn drivers before getting on 80 that it is closed
CMS	West of Summit Interchange 322	Steep Grade ICY warning Advisory speeds
CCTV	High point on cut section 321	Road condition and crash surveillance
Chain Down area	Good tangent section 317 to 310	Separated chain off area
Additional Delineators	335-325	Improve delineation at edge of road
Rumble Strips	Whole Corridor	Provide seat of the pants information to driver during blizzards
Truck Advisory Speeds	334-317	Reduce truck speeds in problem areas
Web Cameras	Not used	Snap shots from CCTV to posted to web site
Length Restrictions	All Wyoming roads by law	Triple trailers and chain law

CMS - Changeable message sign, FBS - Static sign with flashing beacons and remote activation, HAR - Highway advisory radio, CCTV - Closed circuit television

Table 9. Recommended Countermeasures - East Bound

Countermeasure East Bound	Location Approximate Milepost	Primary Use
CMS	West of Laramie 310	Advance information for conditions and route diversion
FBS	312, 314, 317	Tune to.....when flashing
HAR	High point good coverage	Road, weather, closures
FBS	316	Road closure when flashing
CMS	317	Road conditions and closure
Manual road closed gate	317	Physical barrier for closure
Chain up area	313-318	Separated pull off
FBS	On ramp of Summit Interchange 323	Warn drivers before getting on 80 that it is closed west bound
Weather Station	323	Precipitation gauge
CMS	325	Visibility, Road conditions Incident management
CMS	326	Advisory speeds, Visibility, Road conditions
CCTV & Lighting	327	Road condition and crash surveillance
CMS	329	Advisory speeds, Visibility, Road conditions
Weather station	Vedauwoo Interchange	Weather and pavement surveillance
FBS	On ramp of Vedauwoo Interchange 329	Warn drivers before getting on 80 that it is closed west bound
CCTV & Lighting	331	Road condition and crash surveillance
Chain Down area	Good tangent section 332	Separated chain off area
Additional Delineators	325-335	Improve delineation at edge of road
Rumble Strips	Whole Corridor	Provide seat of the pants information to driver during blizzards
Snow Fence	325-333.5	Reduce blowing snow, increase visibility, ground blizzard protection
Truck Advisory Speeds	317-334	Reduce truck speeds in problem areas
Web Cameras	Not used	Snap shots from CCTV to posted to web site
Length Restrictions	All Wyoming roads by law	Triple trailers and chain law

CMS - Changeable message sign, FBS - Static sign with flashing beacons and remote activation, HAR - Highway advisory radio, CCTV - Closed circuit television

Suggested procedures four and five are the most important for corridor wide and long term success. These procedures were; check the corridor for consistent and uniform countermeasure applications, and budget for operations and maintenance. Consistent and uniform messages and treatments will produce

the desired expectations from motorists and should reduce incidents. Without forethought of how the operations and maintenance of the countermeasures will be conducted the technology based items are doomed to premature failure and inconsistent use.

Due to the high volume of trucks that queue up during closures, advance changeable message signs and highway advisory radio should be installed at all large towns on Interstate 80 throughout Wyoming. This will allow staged closures when services are overwhelmed at small communities. Advanced information should also be given in the neighboring states of Utah and Nebraska prior to diversion points.

The annual budget for operations and maintenance of the recommended countermeasures will be a significant heap of money. Cost was not part of this study so no figure is forecast.

CONCLUSIONS

This research presented many countermeasures that state DOTs have employed to reduce commercial vehicle crashes during severe weather. Most countermeasures have benefits for all drivers on interstate highways. The subjective method used in this research to rate the effectiveness of a select few countermeasures should not detract from the fact that these measures are used by state DOTs. The real effectiveness can only be measured by actual crash reduction statistics. The recommended countermeasures based on this approach yielded a good place to start when planning to reduce CV incidents.

The effectiveness of each individual countermeasure in reality is minor compared to the effectiveness of a well thought out integrated system of countermeasures. All too often site specific problems are treated while the rest of the corridor is ignored. Budgets are blamed for this piece by piece approach. It will be difficult to solve interstate or cross state problems when intrastate deficiencies exist. The focus of future highway spending should be on corridor wide treatments that are integrated or work in harmony.

This research found that interstates with the highest truck and traffic volumes utilized the most countermeasures to reduce incidents particularly crashes. Currently, only two of the surveyed routes experienced minor congestion. Twenty years from now as truck traffic continues to increase, six or seven routes surveyed may experience congestion problems. The terrain in which the roads were built limits or excludes expansion. DOT will then be confronted with congestion, mobility and safety problems that will be more difficult to deal with in remote areas. Well planned commercial vehicle incident and crash countermeasure installations will be crucial to this nations safety, mobility and economy as the remote interstate routes increase in truck traffic volume.

ACKNOWLEDGMENTS

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- Mr. Doug Moeller, Montana Department of Transportation

- Mr. Jim Stevenson, Montana Department of Transportation
- Mr. Mike Murphy, Nevada Department of Transportation
- Mr. James Garcia, New Mexico Highway and Transportation Department
- Mr. Mark Christensen, Utah Department of Transportation
- Ms. Shawna Lindsey, Utah Department of Transportation
- Mr. Terry Kukes, Washington Department of Transportation
- Mr. Randy Griesbach, Wyoming Department of Transportation
- Mr. Tim McGary, Wyoming Department of Transportation

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APPENDIX A - TELEPHONE INTERVIEW FORM

State:

Contact name:

Title or position:

Phone number:

Interstate:

The research goal is to find the current Countermeasures for Commercial Vehicle Incidents During Severe Weather on Remote Interstate at your DOT .

1.)Does your DOT have a problem with commercial vehicle incidents (typically crashes) on remote interstates during severe weather ?

2.)Which of the following items does your DOT utilize on or for remote interstates to reduce commercial vehicle incidents during severe weather ? Rate each item with: 1 - not effective, 3-some what effective, 5-very effective.

Restrictions and Advisories

Reduced winter speed limits

Variable speed limits

Reduced truck speed limits

Advisory speeds for trucks

Lane restrictions for trucks

Closures to commercial vehicles but open to other vehicles

Length Restrictions

Traffic and road features

Truck Climbing Lanes

Chain-up areas

Signed truck parking areas

Edge line rumble strips

Additional delineation

Mile marker spacing less than one mile increments

Snow fence

Median turn arounds

Larger or additional pavement markings

Additional warning signs for grades and curves

BRIDGES MAY BE ICY signs

Manual road closed gates

Information Systems

Dynamic or changeable message signs in problem areas
Dynamic or changeable message signs at diversion points
well in advance of problem areas
Weather stations - RWIS
Signs with flashing beacons
Highway Advisory Radio - HAR
511 or toll free number for road conditions
Kiosks in ports of entry or truck stops
Web sites with road and weather conditions and restrictions

Surveillance and Detection

Closed circuit TV - CCTV
Web cameras
Count/speed/classification sites for monitoring
Call boxes

Automated Systems

Ice detection warning systems
Automated bridge de-icers and anti-icers
Dynamic curve warning systems
Automated road closure systems
Automated detouring or trailblazing systems

Decision Making

Documented corridor incident management plan
Computer aided dispatch

3.)Does your DOT use any other countermeasures to reduce commercial vehicle crashes ? Rate these items with the same scale as above.

4.)If your DOT uses dynamic or changeable message signs, are specific messages displayed for commercial vehicles ?

5.)If your DOT uses Closed Circuit TV, is this given to the public or media ?

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**BENEFITS OF URBAN ROUNDABOUTS
IN THE STATE OF MARYLAND**

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SUMMARY

Modern roundabouts have become popular in the State of Maryland. They have beneficial effects on traffic operations and safety, as well as revitalization of declining urban areas. Since the development of its first roundabout in Lisbon, the State has, as of June 2002, implemented nearly 30 roundabouts. They are mostly located in the rural areas. Due to beneficial effects of the modern roundabout on the traffic operations and urban revitalization, local governments are requesting the State's assistance to install more roundabouts in urban areas. As of June 2002, there have been three modern roundabouts installed in urban areas in the State of Maryland.

The researcher documented the benefits of urban roundabouts in the State of Maryland with the case studies of the three modern roundabouts: the Towson Roundabout, Baltimore County; the Annapolis Westgate Circle Roundabout, City of Annapolis, Anne Arundel County; and the Mount Rainier Roundabout, Prince George's County. These three modern roundabouts were fairly new – ranging from a few months for the Mount Rainier Roundabout to over four years for the Towson Roundabout. The Annapolis Westgate Circle Roundabout was 2.5 years old only. The purpose of these roundabouts was to address traffic operations and safety problems as well as urban revitalization issues. There were difficulties obtaining quality “Before” and “After” data for the study, particularly for the effect of these roundabouts on urban revitalization. These data represented a weekday only. Seasonal variations were not accounted. The researcher conducted a questionnaire survey with key government officials and consultants to get some indication about the urban revitalization issues. The author would like, therefore, to caution the readers when interpreting some results.

The study findings clearly show these roundabouts have traffic operation and safety benefits. The average vehicle delay was reduced at all three roundabouts. For example, the delay was reduced 54 percent and 40 percent in the Towson Roundabout, 93 percent and 90 percent in the Annapolis Westgate Circle Roundabout and 38 percent and 40 percent in the Mount Rainier Roundabout during the morning and evening peak hours, respectively. Since the delay is directly related to the level of service, the traffic operation in these roundabouts improved significantly.

The evidence of the Towson and Annapolis roundabouts indicated that the roundabouts reduced the injury accidents significantly. For example, the personal injury accidents reduced by 69 percent in the Towson Roundabout and 80 percent for the Annapolis Westgate Circle Roundabout. However, overall accident rates increased significantly in the Towson Roundabout due to increased “fender bender” property damage accidents. Therefore, the modern roundabouts had mixed results in achieving the safety objective.

The Mount Rainier Roundabout was opened in February of 2002, and so there was no “After” accident data for the “Before” and “After” analysis. For the 1997 through 2000 period, no police reported accidents were found for this location.

In addition, the survey findings indicated that these roundabouts are having positive impact on the urban revitalization.

The researcher found; however, inconclusive results on the effect of these roundabouts on the peak hour traffic volumes and accident frequencies. A pattern on the traffic volume through these roundabouts – whether increasing or decreasing, was not found. Compared to the “Before” condition, the accident frequencies increased significantly in the Towson Roundabout, while the accident frequency decreased in the Annapolis Westgate Circle Roundabout. The effect of the urban roundabouts on the economic revitalization was qualitative only and lacked quantitative data. These should be further investigated at a later date to determine the pattern.

Overall, the researcher established the positive benefits of modern roundabouts in the State of Maryland. He recommends installing additional modern roundabouts in urban areas of the State to achieve dual objectives – traffic operational improvements and revitalization!

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INTRODUCTION

Background

Modern roundabouts started in the United States of America with the construction of two roundabouts in Summerlin, Nevada, in 1990. Prior to this, Americans were not aware of beneficial uses of roundabouts. Europeans and Australians were using modern roundabouts since the 1970s. Modern roundabouts were found to improve safety and operational capacity over the traditional forms of the signalized and non-signalized intersections(L). They are also useful to revitalize urban areas. Since the first two roundabouts were introduced to the country a decade ago, several states joined Nevada to develop roundabouts.

Maryland has been the leader in introducing roundabouts in the United States. The State installed its first roundabout in Lisbon in 1993. Construction of modern roundabouts in the State of Maryland is steadily increasing. The positive effects of the roundabouts on traffic congestion and safety seem to have enhanced their popularity over the traditional signalized or non-signalized intersections. As of May 2002, a total of 29 roundabouts have been installed in the state-- three are in urban areas and twenty-six in the suburban and rural areas. The following roundabouts were installed in urban areas:

- The Towson Roundabout, Towson, Baltimore County;
- The Annapolis Westgate Circle Roundabout, City of Annapolis, Anne Arundel County; and
- The Mount Rainier Roundabout, City of Mount Rainier, Prince George's County.

Local governments are requesting the State's assistance in developing modern roundabouts for addressing traffic congestion and safety issues and, at the same time, they hope, addressing urban decline. They want to use the modern roundabout to revitalize their urban centers.

Generally, when an urban center experiences congestion, particularly during the morning and evening peak hours, the area businesses suffer since they do not get their customers. They start relocating to locations where they can find their customers. The urban center keeps on losing people and businesses and there are a lot of vacant properties. The crime rates go up. The town loses revenue due to loss of property and sale taxes. The town authorities try to revitalize the urban center. They develop a revitalization project that addresses traffic congestion, aesthetic improvement, city crime and incentives for business development and redevelopment. The installation of a modern roundabout is a part of the revitalization puzzle, which addresses traffic congestion, aesthetic improvement and a sense of focal point. The authority improves the town's safety by enhancing public security. Then the people and business start coming back to the urban center again. This is how an urban revitalization project works. Therefore, a roundabout plus streetscaping project, business promotion policies and crime reduction activities will help to revitalize an urban center.

The current studies are addressing modern roundabouts from the engineers' perspectives only as a tool to improve traffic operations and safety as well as a traffic-calming device. Studies from a planner's perspective are not available. There are no studies, which have documented the benefits of modern roundabouts in densely populated, urban centers. There is need for understanding the role of the roundabouts in addressing traffic congestion and safety, as well as, urban revitalization. It will be useful to study the benefits of existing roundabouts in urban areas to assess its continued application in high-density locations. The researcher attempts to document benefits of the three selected roundabouts from the State of Maryland. He also attempted to identify the applications for the study findings for other local jurisdictions within the State of Maryland and other states in the country.

Human factors, such as age, education, etc. are important in understanding and accepting the modern roundabouts in place of traditional signalized or unsignalized intersections. Drivers, pedestrians,

bicyclists and the general public in the area need to be educated about the operational aspects of the roundabout. Only when drivers feel safe to drive through a roundabout, will they use the roundabout. Until then, they will avoid the roundabout and take alternative routes. Similar is the case for pedestrians and bicyclists. Therefore, it may take several years to obtain full benefits of the roundabouts. Since urban roundabouts in Maryland are fairly new, their benefits with respect to operational safety and capacity may be partial only.

The researcher documented benefits of urban roundabouts by evaluating the “Before” and “After” situations of the three urban roundabouts, mentioned above, in the State of Maryland.

Research Objectives

The purpose of this study was to document benefits of modern roundabout in urban areas of Maryland. The researcher focused on the effect of modern roundabouts on the operational safety and capacity of the intersection in the urban areas, as well as their role on urban revitalization and beautification. The observed results were then compared with findings of other studies that were identified from the literature survey.

Specific objectives of this study were the following:

- Study the effect of the urban roundabout in alleviating congestion;
- Study the effect of the urban roundabout in alleviating traffic crashes;
- Identify the effect of the urban roundabout on urban revitalization;
- Identify applications for the study findings.

Research Methodology

The proposed study was conducted using the following approaches: (a) literature survey, (b) data collection, and (c) questionnaire survey.

Literature Survey

A review of current literature was performed in order to examine the previous research works. This included reviewing technical project reports prepared by the Maryland State Highway Administration (MD SHA) on the selected urban roundabouts and articles and workshop papers on the modern roundabout. This provided needed information including project background and "Before" the roundabout information (peak hour traffic volume, accident data, and delay data), roundabout development process, and reasons for constructing the roundabout. The literature survey also included reviewing of articles that contained benefits of the modern roundabout in urban areas from other states in the country and abroad. These documents were identified by Internet search.

Documents related to the selected roundabout projects were collected from MD SHA. Articles and other documents were obtained from Texas Transportation Institute's (TTI) library.

Data Collection

Primary transportation related benefits of the urban roundabouts include reducing congestion; thereby, improving operations; and reducing the number of accidents, particularly injury accidents, which leads to improved traffic safety. The average peak hour stopped delay experienced by motorists is a measure for alleviating congestion in an intersection. The reduction in the number of accidents, by type and severity,

in an intersection measures the improvement of traffic safety. Therefore, delay and accident data are keys to measure the benefits of the roundabouts related to the traffic operations and safety.

This was a comparative study of the “Before” and “After” roundabout conditions of the selected urban roundabouts. The “Before” roundabout condition consisted of the situation when there was a signalized intersection. Ideally, the delay and accident data for both situations were needed to measure the effectiveness of these roundabouts to alleviate congestion and safety. As said earlier, the data used in this study had some limitations. The researcher could not consider seasonal variations by undertaking traffic volume counts at different seasons. The difference between the “Before” and “After” data could be due to the seasonal variation. The readers are, therefore, advised to take precaution for interpreting the study findings.

The following data were collected for the “Before” roundabout and “After” roundabout periods to study traffic operational and safety benefits of urban roundabouts in the State of Maryland:

- A morning and evening peak hour weekday turning movement count at each leg;
- Average peak hour delay, and
- Police reported traffic accidents.

The “Before” roundabout data for this study were taken from the feasibility studies that the MD SHA conducted as part of the alternate development (2)(3)(4). The Towson Roundabout has been studied several times in its four years existence since the blind community of Towson has sued the State for constructing the roundabout that blind persons have difficulty crossing it. The traffic continuously flowed through the roundabout. Pedestrian crossing particularly for the disabled persons like blind persons and the elderly was an issue and it still is. Traffic volume and delay data were collected at the original intersection during morning, midday and evening peak hours in April 1996 and February 1999. The researcher selected the April 1996 data for the “Before” roundabout and the February 1999 data for the “After” roundabout period (5).

The MD SHA conducted “After” counts and prepared a delay study, on Wednesday, June 19, 2002, for the Annapolis Westgate Circle Roundabout and the Mount Rainier Roundabout. A 12-hour (7:00 AM to 7:00 PM) turning movement count at each leg of the roundabout was performed. The turning movement included “IN” from the roundabout into the side street, “OUT” from side-street into the roundabout, and “THRU” vehicles circulating in the roundabout.

Peak hour volume and average delay were measured for each approach leg. The Australian Road Research Board developed SIDRA (Signalized Intersection Design and Research Aid) program was used to compute the overall level of service (LOS) for the roundabout intersections. These data are presented in Tables 2, 3 and 4.

For measuring the traffic safety benefits of the roundabouts, the police reported traffic accidents of the 3 to 5 years prior to the completion of the roundabout were obtained from the MD SHA Office of Traffic and Safety. The Towson Roundabout was constructed during 1998 and 1999 and, therefore, no accident data were analyzed for these years.

No police reported accidents were found for the Mount Rainier Roundabout during 1998 through 2000. This roundabout was built in 2001 and so this was considered the construction year. It shows that this intersection had no traffic safety issues, except speeding vehicles and pedestrian crossing. No accident data for the construction year was used for this analysis. This was opened to traffic in February 2002; therefore, we did not have “Before” and “After” accident data for this roundabout.

An indicative survey, which is discussed below, of selected local and state agency, and consultant representatives was conducted to obtain some non-traffic, urban revitalization related benefits of the roundabouts.

Questionnaire Survey

In a four-week time frame of this study, a scientific questionnaire survey cannot be conducted. Instead, a questionnaire survey, with 10 general qualitative questions was conducted by interviewing 13 key local and state government officials and consultants who were involved with the selected urban roundabouts in Maryland. A copy of the survey questionnaire is presented in Appendix A.

The purpose of this survey was to obtain benefits, such as revitalization and beautification effects of the modern roundabouts in urban areas that were not readily available and/or were qualitative in nature. The survey results provided some indications about the non-quantifiable benefits such as their effect on revitalization.

The basis for the selection of the survey respondents was that they played a key role in the planning, designing, construction, monitoring, and/or maintenance of any one of the selected roundabouts. The selected respondents for the survey included local government officials of the city and/or county, where the selected roundabouts were physically located, and state government officials of MD SHA, and the consultants who were directly involved either in designing and evaluating the selected roundabouts. A few respondents were also selected to represent business associations who directly took part in public education of the roundabout installation. Besides the survey respondents, the researcher contacted, by phone, several officials of the local and state government agencies to determine the benefits of the selected urban roundabouts in Maryland. A list of contact persons, including those who were interviewed is presented in Appendix B.

This survey was conducted, first, by calling the respondents by phone and stating them the objectives of the questionnaire survey. It was followed by e-mailing the survey questionnaire to 30 selected Maryland State and local government officials and consultants and asking the respondents to submit their completed questionnaires by a due date. Finally, the researcher contacted them for clarifying some responses and obtaining additional information. Altogether 13 respondents returned the completed questionnaires.

There were no sufficient data for statistical analyses. The responses were tabulated and a summary of the findings was used in this study. The summary response table is presented in Appendix C.

Scope of Work

The purpose of this study was to evaluate the benefits of modern roundabouts in urban areas with empirical investigation from the State of Maryland. As of May 2002, there were three modern roundabouts – the Towson Roundabout, Towson, Baltimore County; the Annapolis Westgate Circle Roundabout, City of Annapolis, Anne Arundel County; and the Mount Rainier Roundabout, City of Mount Rainier, Prince George’s County - in urban areas of Maryland. They were located in the business district and served as a “gateway” to the city. The researcher documented the benefits of these urban roundabouts in this study.

Organization of Report

This report was organized in a logical sequence. Background, research objectives, research methodology and study scope were presented in the introduction. The introduction was followed by the literature reviews where articles that addressed the benefits of urban roundabouts were reviewed. The three urban roundabouts from the State of Maryland, selected for this study, were then overviewed. The researcher presented data analysis thereafter. Traffic volumes, delays and Level of Service, and accident analysis

were discussed for each of the three roundabouts. The results of the survey were summarized next. Summary of the findings and applications followed thereafter.

LITERATURE SURVEY

It is important, first, to define some of the terms and concepts that this study deals with. Then some of the research findings of the earlier studies related to the benefits of urban roundabouts were overviewed.

What is an Urban Area?

The U.S. Census Bureau defined, for the U.S. Census 2000, a settlement as “urban” with all territory, population and housing units located within an urbanized area or an urban cluster. The Bureau delineated the boundaries of an urban area and an urban cluster to include densely settled territory, which consists of a core census block groups or blocks that have a population density of at least 1,000 people per square mile and surrounding census blocks that have an overall density of at least 500 people per square mile. Under certain conditions, the Bureau also incorporated less densely settled territories in an urban area or an urban center.

For the purpose of this study, an urban area is a human settlement, as designated by the Bureau of the Census, with a population of 5,000 or more, a population density of, at least, 1,000 people per square mile, a commercial center like Business District, a county or city administrative headquarter and acts as a gateway to the town.

What is an Urban Roundabout?

An urban roundabout for this study is defined as a modern roundabout that is located in a Business District of a town and acts as a gateway to the town.

What is a Modern Roundabout?

A modern roundabout is a form of intersection design that has yield-at-entry points for the approaching vehicles; right-of-way to vehicles within the roundabout (circulating vehicles); and allows traffic flow in one direction, counter-clockwise, around a central island. Federal Highway Administration published, in 2000, its first guideline on roundabouts entitled “Roundabouts – An Informational Guide”. This guideline is a comprehensive source of information about modern roundabouts. This guide provides the following characteristics of a modern roundabout (6):

Yield-at-entry – Entering vehicles (approach vehicles) must yield to the circulating vehicles. Vehicles in the circulatory roadway have the right-of-way and all entering vehicles on the approaches must wait for a gap in the circulating flow.

Deflection of Entering Traffic – Entering traffic faces a narrow, but adequate radius at the entry approaches and circulatory roadway and central island, which deflects vehicles to the right, thus causing low entry speeds of 30 miles per hour or less.

Entry Flare – The approach widens at the entry point to multi lanes to accommodate additional vehicles and storage at the yield line – this increases capacity.

Splitter Island – This is a raised island on the entry and exit approaches of the roundabout. This is designed to separate traffic moving in opposite directions, act as a deflector for an entering vehicle and allow pedestrians to cross in two phases (safe haven for pedestrians). The splitter islands provide

opportunity for landscaping and beautification. According to the FHWA Manual, pavement markings may only act as a splitter island for mini-roundabouts.

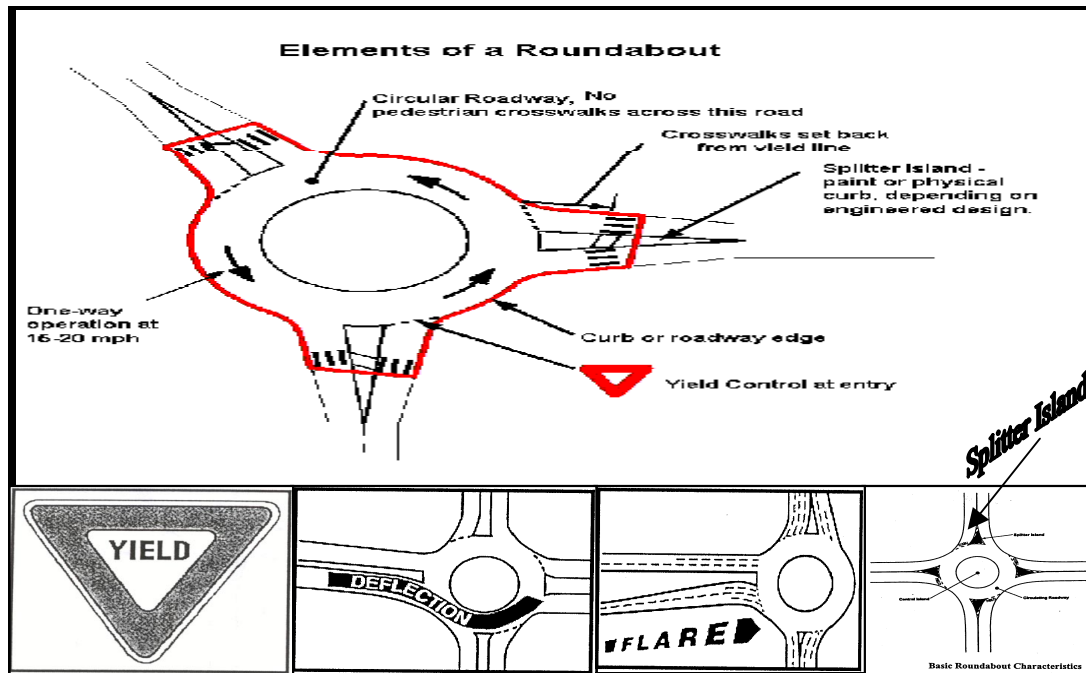


Figure 1. Elements of a Roundabout. – Yield-at-entry, Deflection, Flare and Splitter Island

Central Island – An island at the center is a key feature of a roundabout, which acts as a deflector to the circulating (counter-clockwise) vehicles. This also provides an excellent opportunity to enhance the aesthetics of the roundabout by landscaping, installing water fountains, and/or showing masterpieces of arts like statues.

Other Characteristics – Pedestrian crossing and aprons are other features of a modern roundabout. Pedestrian crossing is provided behind the yield line to cross the legs of the roundabout. Because of the presence of a splitter island between the opposite moving vehicles on an approach leg, pedestrians can cross the approach leg in two stages. Pedestrians can stop at the splitter island. Since the drivers must yield to pedestrians, pedestrian crossing is theoretically safer in the roundabouts than in a signalized intersection.

An apron is a mountable portion of the central island adjacent to the circulatory roadway. This is used in smaller roundabouts to accommodate the wheel tracking of large vehicles like a tractor-trailer. Parking is prohibited, at all times, within the circulatory roadway and at the entries. Good sight distance, good lighting, good signing and no crosswalks across the circulatory roadway are other features of the modern roundabouts.

In short, a modern roundabout is a circular intersection in which traffic moves counter-clockwise around a central island. All entering traffic yields the right-of-way to circulating traffic.

Traffic and Safety Terminology

Delays: Delays at roundabouts consist of queuing and geometric delays. Queuing delay is the delay of vehicles waiting in a queue. Geometric delay is the delay caused to vehicles due to the existence of the

roundabout junction. It occurs because motorists must reduce their speed to negotiate the junction and must also deviate from a direct path.

Level of Service: Level of service (LOS) is a qualitative measure describing operational conditions within a traffic stream. Generally, LOS is described in terms of service that measures such as speed and travel time, freedom to maneuver, traffic interruptions, comfort, and convenience. It is measured in “A” through “F”- as “A” being an excellent service and “F” the worst one. Normally, LOS “A” through “D” indicate acceptable operation conditions, while LOS “E” and “F” indicate unacceptable operation conditions.

Control delay, which includes queuing and geometric delays, is used to compute the LOS for a modern roundabout. The LOS based delay is described in the Highway Capacity Manual(7). The author used this method to compute the LOS by using Table 1.

**Table 1. Level of Service Definition based on Delay (HCM Method)
Control delay, including geometric delay, per vehicle in second (d)**

Level of Service	Signals and Roundabouts	Stop and Give-Way (Yield) Signs
A	$d \leq 10$	$d \leq 10$
B	$10 < d \leq 20$	$10 < d \leq 15$
C	$20 < d \leq 35$	$15 < d \leq 25$
D	$35 < d \leq 55$	$25 < d \leq 35$
E	$55 < d \leq 80$	$35 < d \leq 50$
F	$80 < d$	$50 < d$

The researcher reviewed major research on modern roundabouts. There were no studies that dealt with the benefits of modern roundabouts in urban areas in the United States. Since the roundabout concept has been recently introduced to this country, the research community has not gathered enough empirical data even to conduct basic research on safety and operational benefits of roundabouts. A scientific study of the benefits of modern roundabouts, particularly with a focus on revitalization, in urban areas is not available. Therefore, the researcher reviewed the available studies irrespective of the location – urban or rural. They were not separated by location. The summary of this review is presented below:

Benefits of Urban Roundabouts

General

Researchers claim that modern roundabouts can reduce injury accidents, traffic delays, fuel consumption, air pollution and operating costs, when designed properly and placed correctly (8). In addition, modern roundabouts have been recently installed in urban areas of the United States to revitalize the declining areas.

One author summarized the benefits of modern roundabouts and their future, by quoting Michael J. Wallwork, an expert on the modern roundabouts in the United States, as follows (9):

"In their search for a better method to control conflicts at intersections, some progressive traffic engineers are now using modern roundabouts. The reason is that modern roundabouts are safer, cheaper more efficient, have a higher capacity, and can be very attractive—especially as a gateway to cities and communities. I predict that engineers will increasingly realize that traffic signals are not the cure-alls that they have been promoted to be," Says Mr. Wallwork *"Roundabouts will be used in residential streets to reduce speeds and crashes, and on arterial roads to reduce crashes and provide a higher capacity. In all instances, they are more cost effective and aesthetically pleasing, leading to public acceptance first, and public preference in the foreseeable future."* added Mr. Wallwork.

Traffic Safety Benefit

Roundabouts were found to be one of the safest forms of intersection control. They have reduced 50 to 90 percent of collisions at intersection compared with two-way stop control or traffic control intersections (8). A researcher, who analyzed 11 U.S. intersections that were converted to roundabouts, found that, compared to the original intersections, the roundabouts reduced the average annual accidents by 37 percent; injury accidents by 51 percent and property damage accidents by 29 percent. The researcher of this study also found that the single-lane roundabouts operate more safely than two-way stopped controlled intersections (10). One of the reasons roundabouts are safer is because they have fewer conflict points than conventional intersections. The more conflict points, the greater the potential for accidents. For example, vehicle-to-vehicle conflict points for a four single lane approach are 32 versus 8 in a modern roundabout with four single-lane approaches (6).

A researcher in another study found that conversion to roundabouts resulted in about 50 percent fewer accidents than two-way stop or signalized intersections, and 60 percent to 90 percent fewer fatal and serious injury accidents (11).

A "Before" and "After" comparative study of six modern roundabouts in Florida, Maryland and Nevada revealed a reduction in accident frequency. Originally, these were "T" and cross intersection (both stop controlled and signalized) and were then converted to modern roundabouts. The reduction in the accident frequency was statistically significant (12). A researcher in the 1998 study of single-lane roundabouts in two U.S. states (Maryland and Florida) found that they reduced accident rates and frequencies and also reduced control delay (13).

A researcher of the 1990 study of 202 accidents at 179 urban roundabouts in France recommended the following (14):

- Ensure motorists recognize the approach to the roundabout;
- Avoid entries and exits with two or more lanes except for capacity requirements;
- Separate the exit and entry by a splitter island;
- Avoid perpendicular entries or very large radii;
- Avoid very tight exit radii; and
- Avoid oval-shaped roundabouts.

The last design recommendation was interesting in the context of the Towson Roundabout in Maryland. The Towson Roundabout was an oval-shaped roundabout. Another factor could be the driver's confusion about the driving through the roundabout.

In the merit of safety improvements, a transportation professional has proposed the removal of traffic signals in Maryland, Virginia and Washington, DC, and replacement with modern roundabouts (15).

Traffic Operational Benefit

Roundabouts allow continuous flow of traffic through the intersection. All traffic movements are given equal chance to enter into the intersection. Forty to 50 percent time is reported to have been lost at signalized intersections with left turn phasing. Modern roundabouts have raised intersection capacity by 10 percent to 30 percent without geometric changes, when they replaced signalized intersections (16). Roundabout capacity increased most significantly where there was a large proportion of left-turn vehicles. Additional capacity was achieved by enlarging the roundabout and increasing the entry flares (17). A researcher in another study reported that roundabout can handle greater capacities at higher level of service. A single lane roundabout can handle 2,500 to 2,800 vehicles per hour, which corresponds to an ADT of 30,000 (1). Since there is only yield-at-entry control, roundabouts usually have less delay than signalized intersections. The Surveyor's Society of United Kingdom in a study found that a roundabout reduced the 2 km peak-hour queue at the signalized intersection to a queue of only 50 meter. A roundabout reduced the delay by a few seconds per vehicle at a two-way stop intersection and by a couple of minutes at another two-way stop intersection (18).

Earlier studies attributed 40 percent of delay in urban areas to traffic signal inefficiencies (19). Signals cause delay by stopping vehicles unnecessarily on red lights at low to moderate volumes, when no traffic is using the green light. At high volumes, traffic signals reduce intersection capacity, particularly at sites where the high proportion of left-turners requires a left-turn phase.

Urban Revitalization Benefit

Aesthetics: Modern roundabouts provide opportunities to enhance the beauty of town centers or gateways, because they provide opportunity for landscaping on center islands and splitter islands (8). Pavements could also be altered to make it attractive. Aesthetically pleasing lighting could be installed. The roundabouts' potential aesthetic value could be used to spur economic revitalization in the town centers. Private developers are attracted with the aesthetically pleasing environment in the town centers.

Traffic Calming Benefit

Drivers have to slow down to comfortably negotiate the entry approaches and the deflectors. Modern roundabouts are designed for slowing the traffic. They act as an effective speed reducers in residential areas and entrances to a downtown area. This could help urban revitalization by enabling pedestrian movement across the roundabouts. This is because roundabouts reduce vehicle speed, traffic has to yield to pedestrians, and pedestrians can cross an approach in two stages. They can stop at splitter islands.

Environmental Benefit

Since roundabouts reduce vehicle stop delays, they may provide environmental benefits in terms of reduced air and noise pollution, and fuel consumption over conventional signalized intersections.

Operation & Maintenance Cost Saving Benefit

Unlike traffic signals, modern roundabouts do not have signal equipment that require constant power, periodic light bulb and detection maintenance, and regular signal timing updates. Roundabouts need only periodic landscape and sign maintenance. Also, the service life of a roundabout is 25 years versus 10 years for a traffic signal (20).

Other Benefits

Liability: Traffic signals are a liability to an operating authority in times of malfunction. The liability in a roundabout is with the entering driver as it is his or her responsibility to yield (*L*).

Equal access: Roundabouts provides equal opportunity to pass through to all approaches. Gaps are available to all drivers (*L*).

Trip Time Perception: the perceived travel time is often shorter due to the reduction in the stopped time (*L*).

Disadvantages of the Urban Roundabouts

Modern roundabouts have some disadvantages. They are as follows:

Signal Progression: Some opponents argue that modern roundabouts disrupt the traffic “platoon” flow in a coordinated traffic signal system in a corridor. Roundabouts, with their yield-at-entry requirement, may reduce traffic progression movement. In fact, it may result in overall system delay in a corridor. To avoid this situation, experts suggest division of the signal system into subsystems separated by roundabouts. Then each signal system should have its own cycle.

Pedestrian Crossing: As required by the traffic rule at the crossings, some drivers do not yield to the pedestrians. This causes safety problems for the pedestrians. Drivers’ education and enforcement of the traffic rules are needed to address this issue. Disabled persons, especially the visually impaired, face a serious challenge for crossing modern roundabouts. Some additional works – design and education, may be necessary for these issues (*L*).

Cost: Initial construction cost of a modern roundabout especially in urban area is higher than for the signalized intersection. In urban areas, the cost tends to be higher since land value is higher and landscaping, signing, pavement enhancement and lighting are part of the roundabout (*L*).

Public Opposition: Modern roundabouts experience some public opposition from some quarters like disabled community, senior citizens, etc. (*L*).

THE URBAN ROUNDABOUTS IN THE STATE OF MARYLAND

A short description of each of the selected roundabouts is provided below. .

The Towson Roundabout

The seat of the Baltimore County government is located in Towson. With its major institutional, educational, medical, commercial and corporate centers, Towson is a heavily urbanized area - second major city after Baltimore City in the region, even though it is not an incorporated entity.

The downtown Towson area, prior to the construction of the roundabout, was declining since many businesses were closing and moving out of the area. The intersection of MD 45 (York Road) at MD 146 (Dulaney Valley Road)/Joppa Road/Allegheny Avenue was controlled by two closely spaced traffic signals. Due to its poor geometric conditions and traffic volumes particularly during peak periods, the intersection was operating very poorly.

Baltimore County proposed in the early 1990s to revitalize the downtown Towson area by constructing a modern roundabout at this intersection and implementing streetscaping projects to the MD 45 and MD 146 corridors through the roundabout to enhance the beauty of the town center area. The County hoped

to reduce accidents, mitigate congestion, and serve as a gateway to the Towson business district. With these, it expected to achieve the downtown Towson's economic revitalization goal. Baltimore County requested MD SHA to assist in the construction of the Towson Roundabout and implement the streetscape projects on the MD 45 and MD 146 corridors through the Towson area.

MD SHA conducted preliminary engineering and the public involvement processes. The Towson Roundabout was officially opened to traffic on February 2, 1998. The roundabout requires entering motorists to yield right-of-way to vehicles in the circle as well as pedestrians crossing the approach legs. Two 18-foot travel lanes are in the circle for circulation in a counter-clockwise direction. Other features of this roundabout include pedestrian lighting, pedestrian signing, pedestrian crosswalks, handicapped curb ramps and yield lines. Several bus stops are provided on all approaches, except on the west approach on Allegheny Avenue. Additional streetscaping, including landscaping and benches are provided around the roundabout.

This is the first modern roundabout in an urban area in the State of Maryland or probably the first one in the United States that is used by a substantial numbers of pedestrians. This is a five legged, oval-shaped roundabout intersection, three legs formed by state roads (north – MD 45, south – MD 45, and north – MD 146) and two legs formed by County roads (east – Joppa Road and west – Allegheny Avenue). A location map of the roundabout is shown in Figure 2.

The roundabout is an oval shape, with a two circular lane roundabout, 140' by 260' outside diameter and 58' by 188' inner diameter. In 1997, the intersection handled 47,600 Average Annual Average Daily Traffic (AADT), with a peak hour volume of 2,771 and 3,952 in the morning and evening, respectively. The roundabout serves as the gateway to Towson and has become a focal point.

The Towson Roundabout has been studied several times in its four years existence since the blind community of Towson has sued the State for constructing the roundabout that the blind persons have difficulty crossing it. There are sizeable populations of elderly and visually impaired living near the roundabout. Motorists do not always yield to the pedestrians as required by the traffic law. Pedestrian crossing particularly the blind persons and elderly is an issue. The Federal Highway Administration and U.S. Department of Justice examined the suit and asked the MD SHA to improve certain features of the roundabout to assist disabled persons in crossing the roundabout. MD SHA made improvements as per their recommendations. The federal agencies were satisfied with the State's improvements.

The Towson Roundabout has been studied several times in its four years existence since the blind community of Towson has sued the State for constructing the roundabout that the blind persons have difficulty crossing. There are sizeable populations of elderly and visually impaired living near the roundabout. Motorists do not always yield to the pedestrians as required by the traffic law. Pedestrian crossing particularly blind persons and elderly are an issue. The Federal Highway Administration and U.S. Department of Justice examined the suit and asked the MD SHA to improve certain features of the roundabout to assist disabled persons in crossing the roundabout. MD SHA made improvements as per their recommendations. The federal agencies were satisfied with the State's improvements.

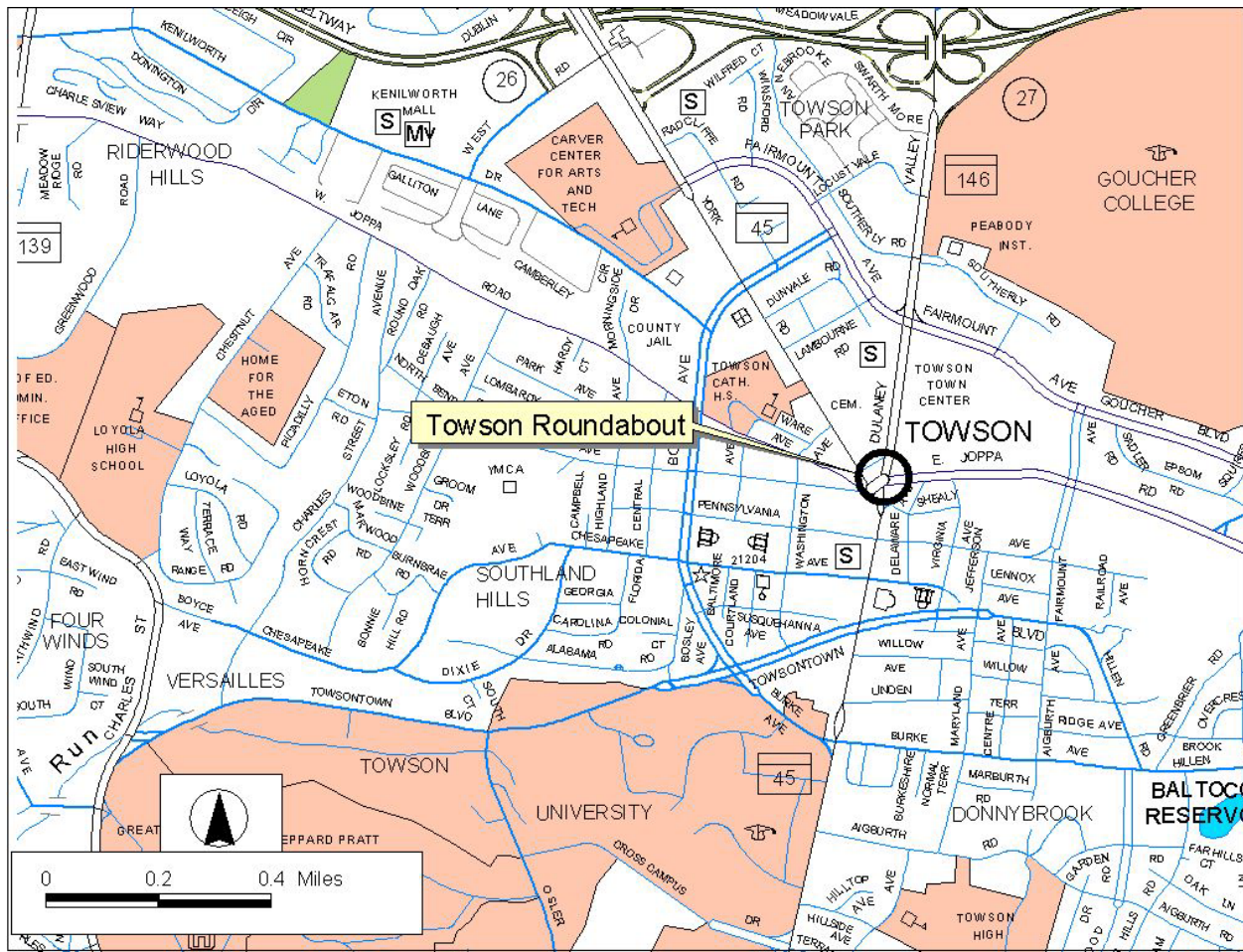


Figure 2. Location Map of The Towson Roundabout

The nearest traffic signals are located approximately 500 feet north of the roundabout at MD 146 and the Towsontown Mall Parking Garage Entrance, 500 feet northeast at MD 45 and Washington Avenue, 750 feet west at Allegheny Avenue and Washington Avenue, 750 feet east at Joppa Road and Virginia Avenue and 500 feet south at MD 45 and Pennsylvania Avenue. MD 45 is a north-south four lane undivided principal arterial, connecting Baltimore City and York, Pennsylvania. MD 146 is also a four-lane north-south divided, arterial originating at the roundabout and extending north toward Jarrettsville.

The “Before” and “After” lane configuration diagrams are presented in Figures 3A and 3B. Photographs of the “Before” and “After” roundabout conditions are shown in Figures 4A and 4B.

Joppa Road and Allegheny Avenue are east-west two- to four-lane undivided arterials, connecting central and eastern Baltimore County from Greenspring to White Marsh. The posted speed is 35 miles per hour along MD 45 and MD 146, and 30 miles per hour along Joppa Road. The AADT through the roundabout in 2001 was 42,800 vehicles per day.

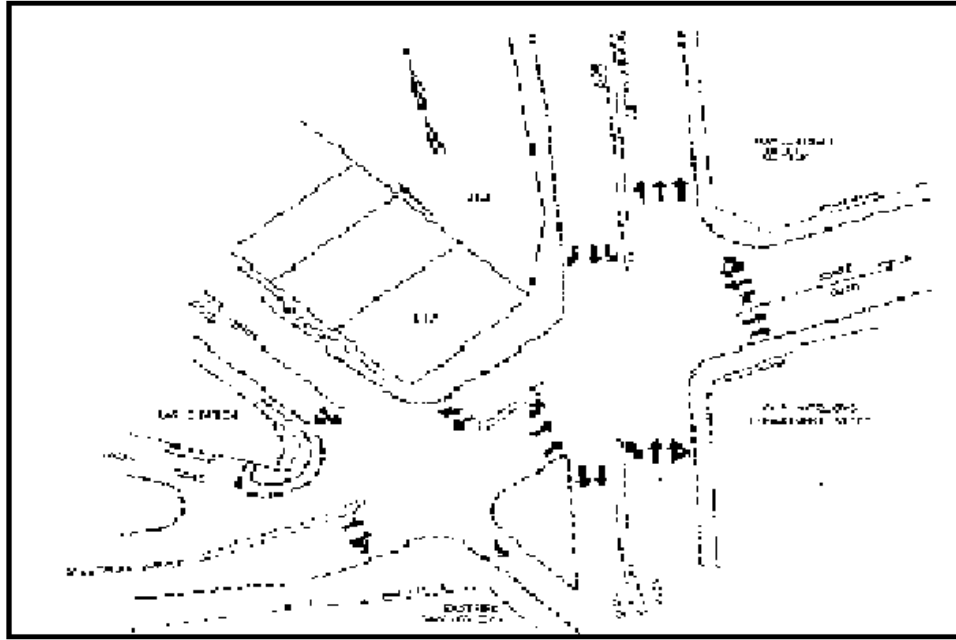


Figure 3A. "Before" Lane Configuration Diagram for the Towson Roundabout, Baltimore County

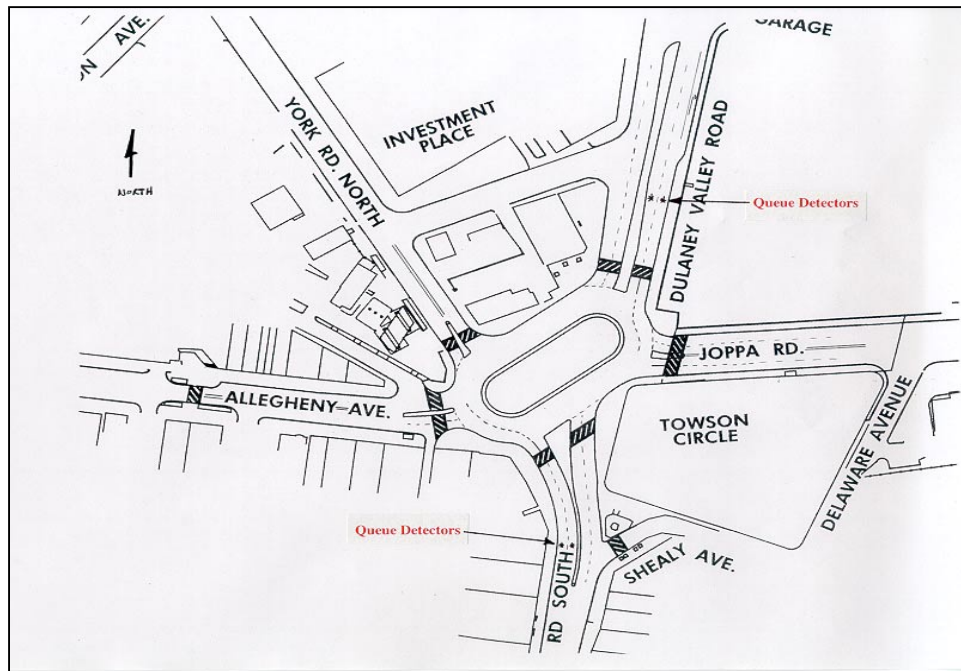


Figure 3B. "After" Lane Configuration Diagram for the Towson Roundabout, Baltimore County



Figure 4A. “Before” Picture - Towson Roundabout



Figure 4B. “After” Picture - Towson Roundabout

The Annapolis Westgate Circle Roundabout

The City of Annapolis is the capital of the State of Maryland and the seat of Anne Arundel County. The city's 1998 Comprehensive Plan proposed the revitalization of the Inner West Street area (MD 450, from Church Circle to the Annapolis Westgate Circle Roundabout) by providing adequate public infrastructures to attract private development (21). The goals for this improvement are to (a) create a gateway entrance to Annapolis, (b) improve aesthetics along this roadway with landscaping and streetscape treatments; (c) improve pedestrian and bicycles access and (d) bury overhead utilities (electricity wires, phone lines, cables, etc.).

As part of this proposal, the city proposed to construct a modern roundabout at the intersection of MD 450 (West Street) at MD 435 (Taylor Avenue) / MD 387 (Spa Road). The roundabout concept for this intersection came originally from a local architect. He proposed construction of modern roundabouts on the major approaches or entry points of the city center to act as "gateways." The architect argued that, in addition to the improvement of the traffic operation, this will enhance the urban design of the city and will ultimately lead to economic revitalization.

The City of Annapolis requested the MD SHA to assist in the construction of a modern roundabout at the intersection of MD 450 at MD 435 and MD 387 in 1995.

Prior to the construction of a roundabout, this was a signalized intersection. Due to heavy traffic volumes from north-south and east-west, the motorists experienced long delays during peak hours. The three roads – MD 450, MD 435 and MD 387, were brought together into the roundabout intersection.

This is the second modern roundabout in an urban area in the State of Maryland that is used by substantial numbers of pedestrians. This is a four legged roundabout intersection, all four legs formed by state roads (north – MD 435, south – MD 387, east – MD 450 and west - MD 435, located at the heart of the City of Annapolis, the capital of the State of Maryland. The city maintains MD 450 (West Street), east of the roundabout, including the roundabout itself. A location map of the roundabout is shown in Figure 5.

The City of Annapolis, with the MD SHA's assistance, conducted preliminary engineering and public involvement processes. The roundabout was officially opened to traffic in December 1999. Two 18-foot travel lanes are in the circle for circulation in a counter-clockwise direction. Other features of this roundabout include pedestrian lighting, pedestrian signing, pedestrian crosswalks, handicapped curb ramps, and yield lines. Additional streetscaping including landscaping and benches are provided around the roundabout. The City is planning to install a public art display in the center island of the roundabout.

This is a two-lane roundabout with 168' to 188' outside diameter and 104' to 124' inner diameter. In 1995, the intersection handled 15,150 AADT, with a peak hour volume of 2,139 and 2,341 vehicles per hour in the morning and evening, respectively. As said earlier, this roundabout serves as the gateway to Annapolis's downtown business center and has become a focal point.

The nearest traffic signals are located approximately 1,800 feet north of the roundabout at MD 435 and Rosedale Street, 1,000 feet south at MD 387 and Smithville Street, 2,000 feet west at MD 450 and Glen Avenue and 300 feet east at MD 450 and Amos Garrett Boulevard. MD 450 is an east-west four-lane undivided arterial, connecting the City of Annapolis and US 50 and I-97. MD 387 and MD 435 are two-lane north-south undivided arterials, connecting south and north Annapolis. The posted speed is 25 miles per hour along MD 450 and 25 miles per hour along MD 435 and MD 387. The AADT through the roundabout in 2002 was 13,000 vehicles per day.

Photographs of the "After" roundabout are included in Figure 6. Figure 7 presents a diagram showing the lane configuration of the "After" Annapolis Westgate Circle Roundabout.

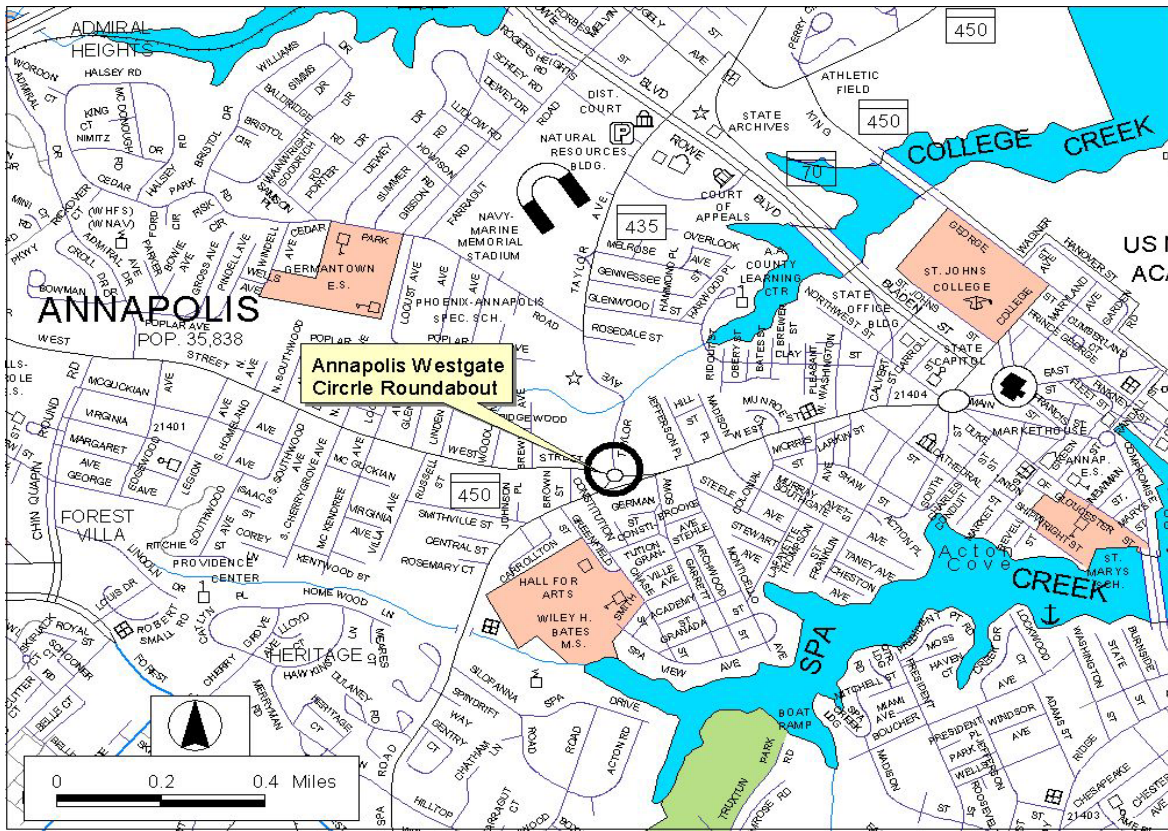


Figure 5. Location Map of the Annapolis Westgate Circle Roundabout, City of Annapolis



Figure 6. “After” Pictures - The Annapolis Westgate Circle Roundabout

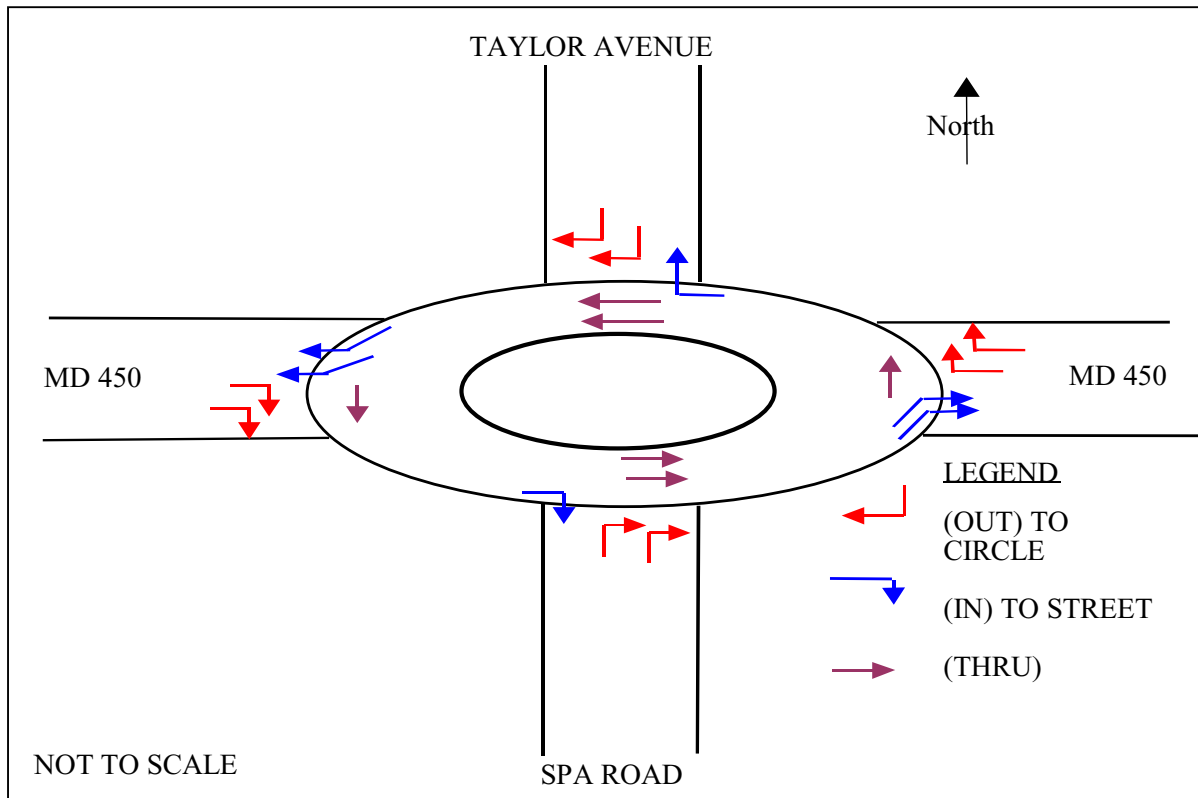


Figure 7. “After” Lane Configuration Diagram – The Annapolis Westgate Circle Roundabout

The Mount Rainier Roundabout

The City of Mount Rainier is a Prince George’s County municipality of approximately 8,500 population, located just outside of Washington, DC. The City is losing its business and population. In fact, the city had 13,000 residents at one time. Due to loss of residents and businesses, the city’s tax base eroded and the City had difficulty maintaining the infrastructure and services. The City proposed to revitalize the US 1 corridor, which passes through the City’s business center – located at the intersection of US 1 at 34th Street/Perry Street.

Speeding motorists at the intersection was identified as a cause for breaking the city business center into two parts – since pedestrian movement was limited, and without people, the business activities could not prosper. The lack of a central place was also identified as a constraint to the City’s revitalization.

In 1996, the University of Maryland’s Landscape Architecture Program conducted a study to develop a streetscape design concept for a roundabout and other major improvements along the US 1 corridor in the town center. In 1997, the city formally requested the MD SHA for streetscape improvements to the US 1 corridor through the City, including construction of a modern roundabout at the intersection. The primary objective of roundabout was to bridge the broad expanse of asphalt that divided the heart of downtown and to provide a much needed visual focal point. The MD SHA conducted preliminary engineering and public involvement during 1998 through 2000.

The Mount Rainier Roundabout was formally opened to traffic in February 2002. This is a six-legged roundabout intersection at US 1 at 34th Street and Perry Street, located near the Washington, D.C., boundary line in the City of Mount Rainier, Prince George’s County, Maryland. A location map is provided in Figure 8.

This is a two-lane roundabout with 140' outside diameter and 82' inner diameter. In 1999, about 20,600 vehicles passed through this roundabout daily with a peak hour volume of 2,133 and 2,365 in the morning and evening, respectively. The roundabout serves as the gateway to Washington, DC and the State of Maryland. This has also become a focal point for the City of Mount Rainier.

The nearest traffic signals are located approximately 800 feet north of the roundabout at US 1 and 37th Street, 800 feet south at US 1 and Eastern Avenue, 750 feet west at 34th Street and Otis Street, 550 feet east at 34th Street and Bunker Hill Road and 800 feet east at Perry Street and 37th Street and 300 feet west at Perry Street and 33rd Street. The US 1 at 34th Street/Perry Street intersection was a six-legged, signalized intersection, with a wide pavement and paved median. The US 1 is a north-south four-lane divided, arterial, connecting Washington, DC and Baltimore. 34th Street and Perry Street are east-west, two lane, and undivided collectors. The posted speed is 25 miles per hour along US 1, and 30 miles per hour along 34th and Perry Streets. The AADT through the roundabout in 2002 was 21,500 vehicles per day.

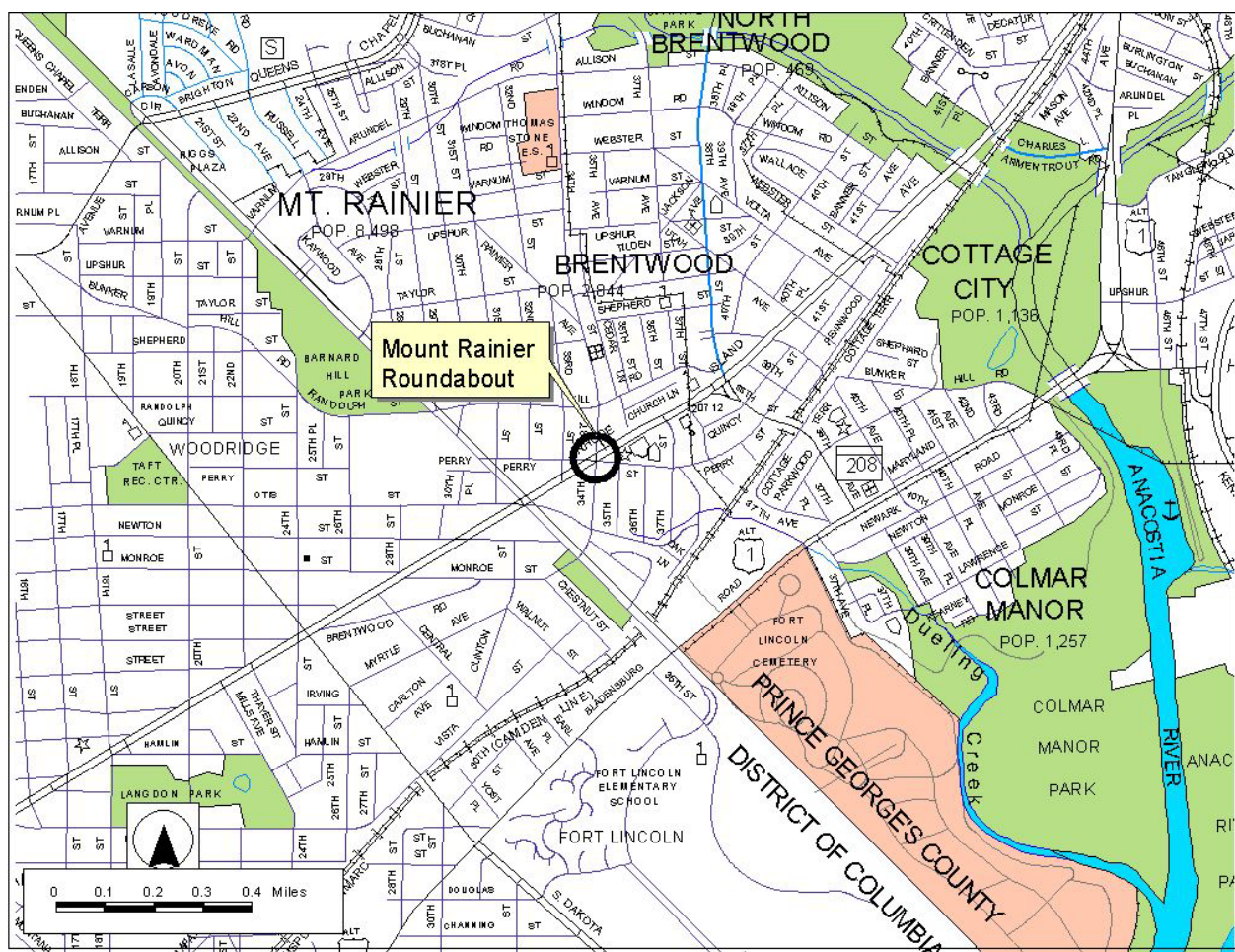


Figure 8. Location Map of the Mount Rainier Roundabout

Figure 9 presents a diagram showing the lane configuration of the “After” Mount Rainier Roundabout. Photographs of the “Before” and “After” roundabout are included in Figures 10A and 10B, respectively.

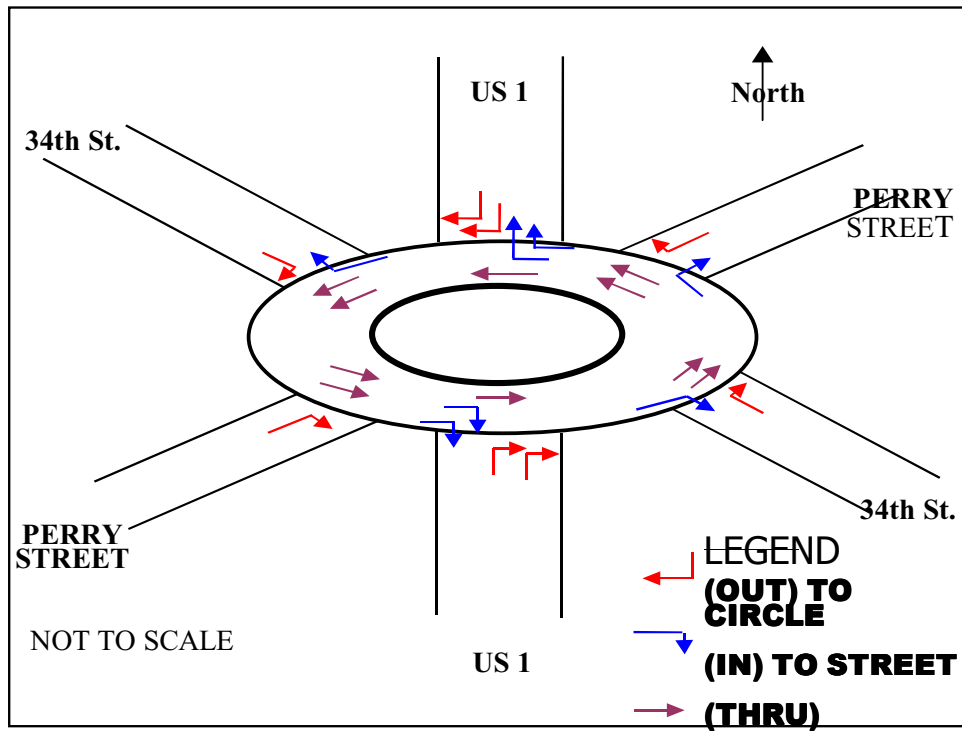


Figure 9. “Before” Lane Configuration – The Mount Rainier Roundabout



“Before” Picture seen from 34th Street

“Before” Picture seen from City Hall

Figure 10A. “Before” Picture – The Mount Rainier Roundabout



“After” Picture seen from 34th Street

“After” Picture seen from City Hall

Figure 10B. “After” Picture – The Mount Rainier Roundabout

DATA ANALYSIS

As mentioned earlier, the urban roundabouts that were selected for this study are fairly new – ranging from four months (Mount Rainier Roundabout) to a little over 4 years (Towson Roundabout). The Annapolis Westgate Circle Roundabout was constructed 2.5 years ago. Generally, full benefits of the roundabouts may be realized only after 5 years or more. This is because drivers, pedestrians, and bikers must become familiar with how the roundabout operates. Also, the roundabout’s impact on the town’s economic development requires a few years to be realized.

For a comparative study like this, there is need for a full set of quality “before” and “after” data. The “before” data were very limited. For example, the traffic analysis of the “before” roundabout was conducted for entry approach volume only. Then the comparative study has to consider only the data set that were used in the “before” the roundabout – even though a full data set is available for the “after” roundabout situation.

Seasonal variation is an important factor for this kind of study. The researcher, however, could not consider seasonal variation in the study. For example, the “After” data for the Annapolis Westgate Circle Roundabout and the Mount Rainier Roundabout were collected during the morning and evening peak hours on Wednesday, April 19th, 2002. The results of this study could be influenced by seasonal variations.

Another issue was traffic counts were conducted using different methodology for the “before” and “after” roundabout situations. This prohibited the use of the 2002 data for the Towson Roundabout that was recently conducted for the MD SHA. For a consistency reason, the February 1999 data were used for this roundabout. This captured the traffic operational benefit of the roundabout for one year only since this roundabout was completed in February 1998.

The readers are advised to the above data limitations while interpreting the study results.

The Towson Roundabout

Traffic Volumes

Traffic counts and a delay studies were conducted in April 1996 at the original intersections during morning, mid-day and afternoon peak hours. This constituted the “Before” roundabout data. Similar data were collected in February 1999 – after one year of opening the Towson Roundabout. This represented the “After” roundabout data.

Table 1 shows peak hour approach and total traffic volumes for the original intersection in April 1996 and the roundabout in February 1999. Only the entry to the roundabout volumes is included in the counts and the exiting vehicles are not counted.

AM Peak Hour. 2,792 total vehicles entered the roundabout during the AM peak hour in the “After” roundabout, down slightly from a 1996 volume of 2,987, a 7 percent decline. The highest entering volume was 1,053 vehicles per hour at southbound MD 146 in the “After” roundabout, which is similar to the volume in the “Before” roundabout.

PM Peak Hour. 3,512 total vehicles entered the roundabout during the PM peak hour in the “After” roundabout, which is similar to the “Before” roundabout volume of 3,455. The highest entering volume was 1,020 vehicles at northbound MD 45 in the “After” roundabout, which is approximately 7 percent lower than the “Before” roundabout volume of 1,096.

This decline of 7 percent traffic volume in the morning peak hour and no change in the evening peak hour could have been due to seasonal and daily variations.

See Figures 11A and 11B for the Peak Hour Volume Counts for the “Before” and “After” Roundabout Conditions.

Delays and Level of Service

The Australian Road Research Board developed the SIDRA (Signalized Intersection Design and Research Aid) software program that can be used to estimate capacity and performance (delay, queue length, stops) for all types of intersections, including roundabouts. This software was used to estimate the average stopped delays. Once the average stopped delay was calculated, this delay was converted to Level of Service using Table 1.

Stopped delays were measured for all approaches during the morning, midday, and evening peak hours on February 23, 1999 (See Table 2). The average delay per approach vehicle did not exceed 30 seconds for any side street for any peak periods, except southbound MD 45 with a delay of 55 seconds in the evening peak period. Compared to the “Before” roundabout period, the average delay per stopped vehicle in the “After” roundabout decreased consistently in all approaches ranging from 7 percent to 91 percent. The roundabout resulted in a 67 percent delay reduction in the midday peak hour, a 54 percent reduction in the morning peak hour and a 40 percent reduction in the evening peak hour. The southbound MD 45 approach was experiencing greater delays since all the traffic movements are now allowed from this approach; whereas in the original signalized intersection configuration, they were not allowed.

Compared to the “Before” roundabout condition, the LOS improved significantly for many approaches or remained the same for a few approaches during the AM, midday or PM peak hour periods. The LOS during the morning peak hours improved at least one level at all approaches. During the evening peak hours, the LOS improved 3 levels to LOS “A” for the Southbound MD 146 and 2 levels to LOS “C” for eastbound Joppa Road. However, these operational improvements could have resulted due to daily and seasonal variations – which the researchers did not consider in the analysis. See Table 2.

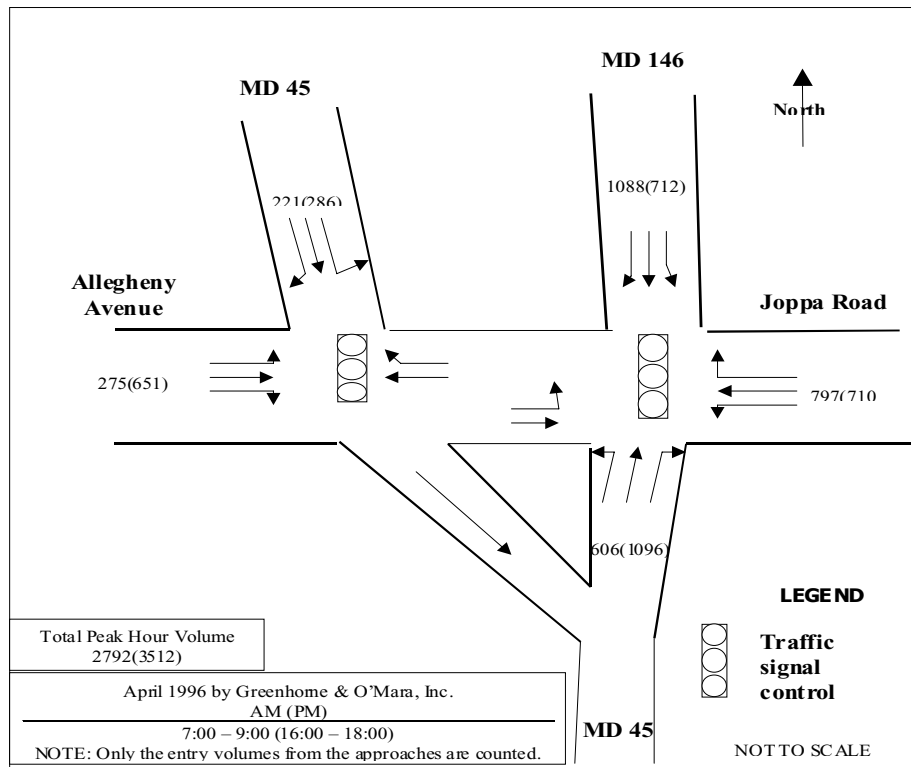


Figure 11A. "Before" Lane Configuration and AM/PM Traffic Volumes for the Towson Roundabout

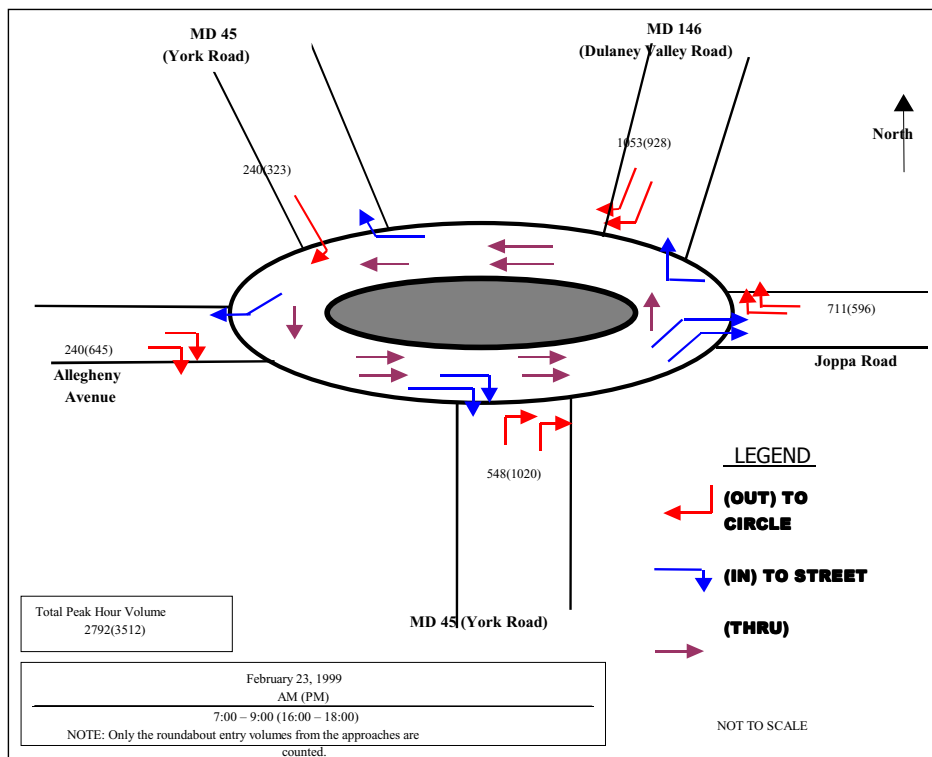


Figure 11B. "After" Lane Configuration and AM/PM Traffic Volumes for the Towson Roundabout

Table 2. “Before” and “After” Peak Hour Volume, Average Delay and Level of Service for The Towson Roundabout

Particular	NB MD 45			SB MD 45			SB MD 146			RB Joppa Road			WB Joppa Road			Total		
	AM	Mid-day	PM	AM	Mid-day	PM	AM	Mid-day	PM	AM	Mid-day	PM	AM	Mid-day	PM	AM	Mid-day	PM
"Before" - April 1996 (Peak Hour: AM - 7:45 to 8:45; PM - 17:00 to 18:00)																		
Peak Hour Volume	606	934	1,096	221	358	286	1,088	813	712	275	447	651	797	629	710	2,987	3,181	3,455
Average Stopped Delay (Sec/Veh)	22	20	15	34	36	40	14	28	37	25	42	69	33	34	31	128	160	192
LOS	C	B	B	D	D	D	B	C	D	C	D	E	C	C	C			
"After" - February 23, 1999 (Peak Hour: AM 7:00 to 9:00; PM - 16:00 to 18:00)																		
Peak Hour Volume	548	839	1,020	240	349	323	1,053	694	928	240	379	645	711	393	596	2,792	2,654	3,512
Average Stopped Delay (Sec/Veh)	5	8	14	30	21	55	6	4	4	15	12	29	3	8	14	59	53	116
LOS	A	A	B	C	C	D	A	A	A	B	B	C	A	A	B			
Difference between "Before" and "After"																		
Peak Hour Volume	-58	-95	-76	19	-9	37	-35	-119	216	-35	-68	-6	-86	-236	-114	-195	-527	57
%	-10%	-10%	-7%	9%	-3%	13%	-3%	-15%	30%	-13%	-15%	-1%	-11%	-38%	-16%	-7%	-17%	2%
Average Stopped Delay (Sec/Veh)	-17	-12	-1	-4	-15	15	-8	-24	-33	-10	-30	-40	-30	-26	-17	-69	-107	-76
%	-77%	-60%	-7%	-12%	-42%	38%	-57%	-86%	-89%	-40%	-71%	-58%	-91%	-76%	-55%	-54%	-67%	-40%

Source for the "Before" and "After" Roundabout Data:

"Towson Roundabout - Before and After Studies". A Technical Memorandum prepared by Greenhorne & O'Mara, Inc. for the Maryland State Highway Administration, May 12, 1999.

"Towson Roundabout, Baltimore County" A Study by the Sabra, Wang & Associates, Inc, for the Maryland State Highway Administration, March 16, 1999.

Accident Analysis

The accident analysis is based on data for the period from January 1 1993 to December 31, 1997 for the “Before” roundabout and January 1, 1999 to December 31, 2001 for the “After” roundabout. There were on average 6.8 accidents per year in the “Before” roundabout, while this was increased by 62 percent in the “After” roundabout, to 11 accidents per year. This is also indicated by the accident rate. The researcher also calculated the accident rate based on the million vehicle entering to the roundabout. The million vehicle entering data were unavailable for 2001. So the accident rate for the “After” roundabout condition was calculated based on the 1999 and 2000 figures only.

The “Before” accident rate was 0.41 accidents per million vehicle entering (acc/mve) and “After” accident rate was 0.86 acc/mve – which is 110 percent higher than the “Before” roundabout. In addition, the accident rate in 2000 in the “After” roundabout was statistically significant, indicating that this rate is higher than similar state maintained road network elsewhere in the State. Also the average number of

accidents per year increased by 160 percent. This shows that the number of accidents has increased in the “After” roundabout compared with the “Before” roundabout. Although the annual average number of accidents in the “After” roundabout has resulted in an increase of 160 percent, personal injury accidents decreased by 69 percent. The reported personal injury accidents accounted for 62 percent in the “Before” roundabout, compared to only 8 percent in the “After” roundabout. Average annual number of property damage crashes increased by 527 percent in the “After” roundabout than the “Before” roundabout (See Table 3A).

Table 3A. “Before” and “After” Accident Information – Severity and Accident Rates, for The Towson Roundabout (1993-2001)

Severity	“Before”							“After”					% Average Annual Change	
	1993	1994	1995	1996	1997	Total	Annual Average	1999	2000	2001	Total	Annual Average		
Fatal	0	0	0	0	0	0	0	0	0	0	0	0	0	0%
Injury	4	2	4	7	4	21	4.2	0	3	1	4	1.3	-69%	
Property Damage	1	2	4	3	3	13	2.6	16	14	19	49	16.3	+527%	
Total	5	4	8	10	7	34	6.8	16	17	20	53	17.7	+160%	
Accident Rates/MVE							0.41	0.72	1.00*	1.28		0.86	+110%	
Injury Accident Rate/MVE							0.26					0.08	-69%	
Million Vehicle Entering (MVE)						81.9	16.4	22.3	17.0	n.a.	38.0	19.0		

*Significantly higher than the statewide rate.

The type of collision was also analyzed for the “Before” and “After” roundabout periods. The number of sideswipe, angle, and rear end crashes increased 3,750 percent, 200 percent, and 150 percent, respectively, in the “After” roundabout than the “Before” roundabout. However, the roundabout successfully eliminated the left-turn, fixed object, and pedestrian accidents. (See Table 3B.)

Accident rates were much higher in the “After” roundabout, which could be attributed to the oval shape of the roundabout and driver unfamiliarity with roundabout operations. It seems that the Towson Roundabout’s oval shape was one of the contributing factors for increased accidents. The oval shape roundabout led to varying speed levels of the circulating vehicle inside the roundabout and this potentially may have caused accidents. Also, literature showed that a circular roundabout was safer than an oval roundabout.

The drivers seem to be confused about driving through the roundabout. Towson faces a significant challenge for educating drivers since there are significant elderly living here and new drivers from the region pass through the roundabout daily. Another reason could be that the researcher had only 3 years of accident data. The data may have been regressed towards the mean.

These findings indicate that there was a mixed success in the safety aspect. Compared to the “Before” condition, the overall accident frequencies increased significantly, but the personal injury accidents

decreased substantially. The study also showed that the property damage accidents increased manifold – indicating increased fender bender accidents in the “After” roundabout period.

Table 3B. “Before” and “After” Accident Information – Type of Collision, for The Towson Roundabout (1993-2001)

Collision	“Before”							“After”					%Average Annual Change
	1993	1994	1995	1996	1997	Total	Annual Average	1999	2000	2001	Total	Annual Average	
Angle	0	1	3	0	1	5	1.0	2	6	1	9	3.0	+200%
Rear End	3	1	3	4	3	14	2.8	6	6	9	21	7.0	+150%
Fixed Object	0	1	0	0	0	1	0.2	0	0	0	0	0.0	-100%
Opposite Direction	0	0	0	0	0	0	0.0	0	0	0	0	0.0	0%
Sideswipe	0	0	0	0	1	1	0.2	8	5	10	23	7.7	+3750%
Left Turn	2	1	1	2	1	7	1.4	0	0	0	0	0.0	-100%
Pedestrian	0	0	1	1	0	2	0.4	0	0	0	0	0.0	-100%
Other	0	1	1	1	1	4	0.8	0	0	0	0	0.0	-100%
Total	5	5	9	8	7	34	6.8	16	17	20	53	17.7	+160%

The Annapolis Westgate Circle Roundabout

Traffic Volumes

The “Before” roundabout data were taken from traffic counts and a delay study completed on the morning and evening peak hours in February 1997, which was conducted by a consultant for the City of Annapolis. This was performed for documenting the existing traffic conditions for the intersection. Similar “After” roundabout data were collected in June 2002 – after two and half years of opening of the Annapolis Westgate Circle Roundabout.

Table 4 shows peak hour approach and total traffic volumes for the original intersection in February 1997 and the roundabout in June 2002. Only the entry to the roundabout volumes are included in the counts and the exiting vehicles are not counted.

AM Peak Hour. 1,890 total vehicles entered the roundabout during the AM peak hour in the “After” roundabout, which is 10 percent higher to the “Before” roundabout volume of 1,714. The highest entering volume was 738 vehicles at northbound MD 387 in the “After” roundabout, which is significantly higher (156 percent) to the volume in the “Before” roundabout.

PM Peak Hour. 2,236 total vehicles entered the roundabout during the PM peak hour in the “After” roundabout, which is 26 percent higher than the “Before” roundabout volume. The highest entering volume was 626 vehicles at westbound MD 450 in the “After” roundabout, which is approximately 10 percent lower than the “Before” roundabout volume.

The peak hour volume in the Annapolis Westgate Circle Roundabout increased in both the morning and evening peak periods. This shows that this roundabout has positive effect on the traffic volume. Some of these increased volumes may have been due to daily and seasonal variations. The latter was not considered in this study by the researcher. See Table 4.

See also Figures 12A and 12B for the Peak Hour Volume Counts for the “Before” and “After” Roundabout Conditions, respectively.

Table 4. “Before” and “After” Peak Hour Volume, Average Delay and Level of Service for The Annapolis Westgate Circle Roundabout, City of Annapolis

Particular	WB MD 450		EB MD 450		SB MD 435		NB Spa Road		Total	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
"Before" - February 12, 13 and 18, 1997 (Peak Hour: AM - 7:45 to 8:45; PM - 17:00 to 18:00)										
Peak Hour Volume	452	692	574	454	400	473	288	157	1714	1776
Average Stopped Delay (Sec/Veh)	36	53	44	44	40	49	20	12	140	158
LOS	D	D	D	D	D	D	B	B		
"After" - June 19, 2002 (Peak Hour: AM 8:00 to 9:00; PM - 17:00 to 18:00)										
Peak Hour Volume	383	626	319	421	450	625	738	564	1890	2236
Average Stopped Delay (Sec/Veh)	2	2	6	12	4	6	8	6	20	26
LOS	A	A	A	B	A	A	A	A		
Difference between "Before" and "After"										
Peak Hour Volume	-69	-66	-255	-33	50	152	450	407	176	460
%	-15%	-10%	-44%	-7%	13%	32%	156%	259%	10%	26%
Average Stopped Delay (Sec/Veh)	-34	-51	-38	-32	-36	-43	-12	-6	-120	-132
%	-94%	-96%	-86%	-73%	90%	88%	-60%	-50%	-86%	-84%

MD 450 at Spa Rd/Taylor Ave	Before (1995)*		After (2002)	
	AM	PM	AM	PM
LOS	C	C	A	A
V/C	0.805	0.784	0.419	0.397
Average Delay (Sec/Veh)	14	15	8.2	8.4

Source: Maryland State Highway Administration, Highway Information Services Division, 2002

Delays and Level of Service

Average vehicle stopped delays were measured for all approaches during the morning and evening peak hours on February 1997 (See Table 4). The average delay per approach vehicle did not exceed 15 seconds for any side street for any peak periods. Compared to the “Before” roundabout period, the

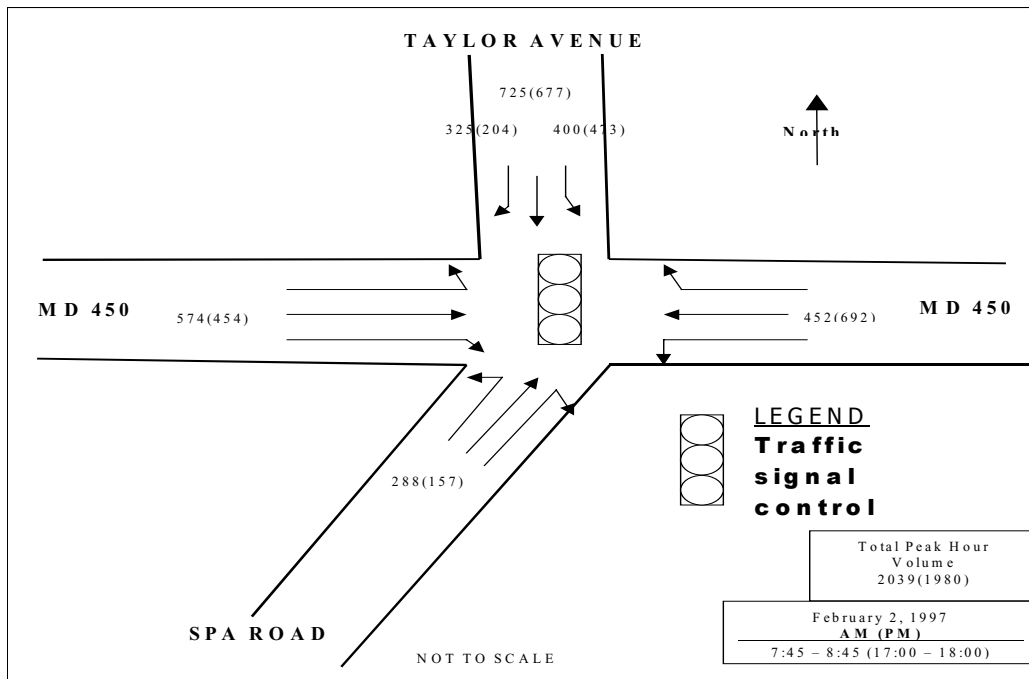


Figure 12A. "Before" Lane configuration and AM/PM Traffic Volumes for the Annapolis Westgate Circle Roundabout

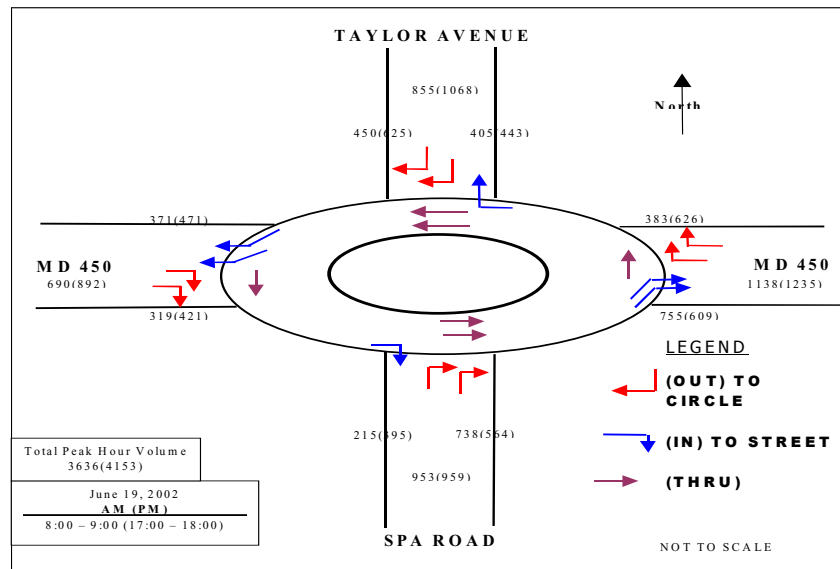


Figure 12B. "After" Lane configuration and AM/PM Traffic Volumes for the Annapolis Westgate Circle Roundabout

average delay per stopped vehicle in the “After” roundabout decreased consistently in all approaches ranging from 50 percent to 96 percent. The roundabout resulted in a 86 percent delay reduction in the morning peak hour and a 84 percent reduction in the evening peak hour (See Table 4).

The Levels of Service of the approaches were “A” during the morning and evening peak hour in the “After” roundabout, except eastbound MD 450 during the evening peak hour where the LOS was “B”. Most of these approaches were operating at LOS of “D” during both morning and evening peak hours in the “Before” roundabout.

MD 450 at MD 435 was a signalized intersection. MD 387 had a posted “STOP” sign at MD 450 and MD 435. Left turning vehicles were required to observe the “STOP” sign. MD 387 was one-way eastbound between MD 450 and MD 435. The Traffic Study (22) describes the traffic conditions for the intersection as follows:

“.... The queue of traffic on MD 450 was not able to completely clear the intersection during one cycle. Westbound MD 450 vehicles queued up to 40 vehicles, at times reaching the next traffic signal on MD 450 at Monticello Avenue. Northbound Taylor Avenue traffic regularly queued onto Spa Road. Southbound Taylor Avenue queued up to 20 vehicles. Many vehicles on Spa Road were observed to disobey the posted “STOP” sign. Two vehicles were observed to make illegal left turns during the AM peak hour.”

The document indicated that the operational condition of the intersection particularly during peak hours (“Before” roundabout) was unacceptable.

A traffic analysis completed in 1995 computed LOS “C” and 15 seconds of average stopped delay for the intersection. Compared to this 1995 finding, the present study showed that the roundabout had a LOS “A” and a stopped delay of 8 seconds – a dramatic improvement.

These findings indicate that the roundabout significantly reduced the vehicle delays, increased capacity and improved traffic flow substantially. Readers are reminded that these findings could be due to daily and seasonal variations- which the researcher did not examine it.

Accident Analysis

The 2000 and 2001 accident data for the “After” roundabout and the 1996 and 1997 accident data for the “Before” roundabout were used for examining the effect of the roundabout on the traffic safety. The analysis shows that overall average annual number of accidents decreased by 58 percent in the “After” roundabout period than the “Before” roundabout period. Both personal injury and property damage accidents decreased significantly in the “After” roundabout than in the “Before” roundabout. Except fixed object accidents, all other types of collisions decreased after the roundabout was constructed. Although there were no significant traffic safety issues at this signalized intersection (“Before” roundabout), the available data presented in this study shows that the roundabout significantly reduced the number of accidents at this intersection (See Tables 5A and 5B).

These findings indicate that compared to the “Before” condition, the roundabout significantly reduced accident frequencies, personal injury accidents, and property damage accidents.

Table 5A. “Before” and “After” Accident Information – Severity and Accident Rates, for The Annapolis Westgate Circle Roundabout (1996-2001)

Severity	“Before”					“After”					% Average Annual Increase (Decrease)
	1996	1997	1998	Total	Annual Average	1999	2000	2001	Total	Annual Average	
Fatal	0	0		0	0		0	0	0	0	0
Injury	2	3	Under	5	2.5	Under	1	0	1	0.5	-80%
Property Damage	3	4	Construction	7	3.5	Construction	2	2	4	2	-43%
Total	5	7		12	6		3	2	5	2.5	-58%
Accident Rates	0.64	0.88					0.35	0.2			
ADT	21086	21739					23819	31100			

Table 5B. “Before” and “After” Accident Information – Type of Collision , for The Annapolis Westgate Circle Roundabout (1996-2001)

Collision	“Before”					“After”					% Increase (Decrease)
	1996	1997	1998	Total	Annual Average	1999	2000	2001	Total	Annual Average	
Angle	0	1		1	0.5		0	0	0	0	-100%
Rear End	2	2		4	2		0	0	0	0	-100%
Fixed Object	0	0	Under	0	0	Under	0	2	2	1	+100%
Opposite Direction	0	0	Construction	0	0	Construction	0	0	0	0	0%
Sideswipe	1	3		4	2		3	0	3	1.5	-25%
Left Turn	0	1		1	0.5		0	0	0	0	-100%
Pedestrian	1	0		1	0.5		0	0	0	0	-100%
Other	1	0		1	0.5		0	0	0	0	-100%
Total	5	7		12	6		3	2	5	2.5	-58%

The Mount Rainier Roundabout

This roundabout was completed in February 2002. The researcher included this roundabout in the study since it met the criteria of the urban roundabout – located at the town center, seat for the City government, functions as a gateway to the town and intended for revitalizing the town center. However, the “After” data of this roundabout were less useful to document its effectiveness. The readers are advised to read the findings carefully so that one would not jump to a conclusion about the modern roundabout.

Traffic Volumes

MD SHA completed traffic counts and a delay study in September 1999 as part of project development. This September 1999 data were considered as the “Before” roundabout data for this study. Traffic count and average delay studies for the “After” data were conducted in June 2002.

Table 6 shows peak hour approach and total traffic volumes for the original intersection in September 1999 and the roundabout in June 2002. Only the entry to the roundabout volumes was included in the counts and the exiting vehicles are not counted.

AM Peak Hour. 1,925 total vehicles entered the roundabout during the AM peak hour in the “After” roundabout, 10 percent lower volume to the “Before” roundabout volume of 2,133. The highest entering volume was 1,297 vehicles at southbound US 1 in the “After” roundabout, which is lower (8 percent) to the volume in the “Before” roundabout.

PM Peak Hour. 2,296 total vehicles entered the roundabout during the PM peak hour in the “After” roundabout, which is slightly lower (3 percent) than the “Before” roundabout volume. The highest entering volume was 1,378 vehicles at northbound US 1 in the “After” roundabout, which is slightly lower (4 percent) than the “Before” roundabout volume.

Both morning and evening peak hour volumes decreased slightly in the “After” roundabout compared to the “Before” roundabout. Exception to this was westbound 34th Street, where the evening peak hour volume increased significantly – 120 vehicles in 2002 versus 45 vehicles in 1999. The slight decline of the “throughput” traffic volume, experts say, may likely be due to some drivers avoiding this newly built roundabout by taking alternate routes. Also, these findings indicate that the roundabout has no effect, so far, on the traffic volumes. Also, this may be due to daily and seasonally variations, which the researcher did not study.

See Figures 13A and 13B for the Peak Hour Volume Counts for the “Before” and “After” Roundabout Conditions.

Delays and Level of Service

The average delay per approach vehicle did not exceed 30 seconds for any side street for any peak periods. Compared to the “Before” roundabout period, the average delay per stopped vehicle in the “After” roundabout decreased consistently in all approaches ranging from 9 percent to 79 percent during the morning peak hour and from 3 percent to 80 percent during the evening peak hour. The roundabout resulted in a 38 percent delay reduction in the morning peak hour and a 46 percent reduction in the evening peak hour (See Table 6.).

Compared to the “Before” roundabout, the LOS improved for some of the approaches. The LOS improved for the northbound US 1 in the morning peak hours and southbound US 1 in the evening peak hours from LOS “C” to LOS “B”. Side streets like 34th Street experienced a dramatic improvement on the operations. For example, the LOS of the eastbound 34th Street improved from LOS “D” in the “Before” roundabout to LOS “A” in the “After” roundabout. Due to short “After” roundabout data, the finding should be interpreted cautiously.

It is clear that compared to the original intersection, the roundabout reduced the vehicle delay significantly and also improved the traffic operations.

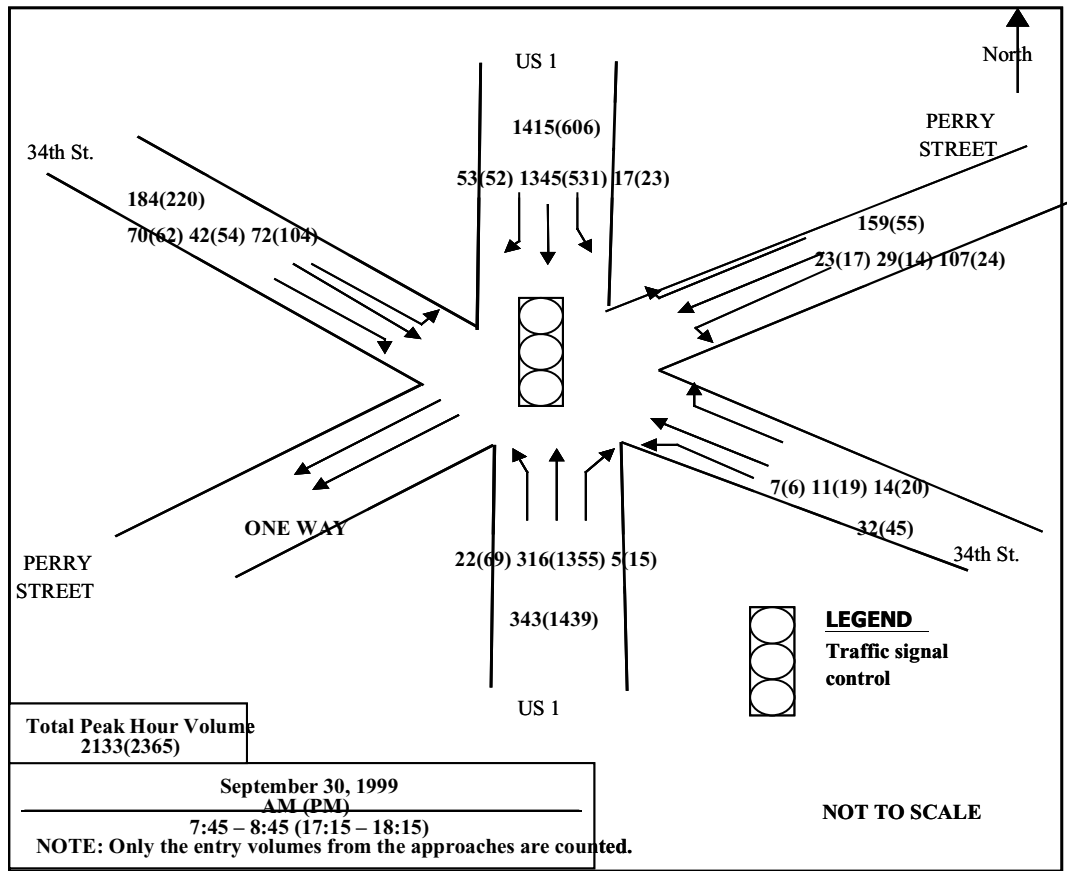


Figure 13A. “Before” Lane Configuration Diagram of the Mount Rainier Roundabout, City of Mount Rainier

Accident Analysis

As said earlier, this roundabout was completed in February 2002. There are no “After” roundabout data on accidents. This intersection, prior to installation of the roundabout, had no safety issues except pedestrian crossing. The primary objective of the roundabout construction at this intersection was to revitalize the town center by promoting pedestrian friendly intersections. There were no police reported accidents during 1998 through 2000 at this intersection. In 2001 (the roundabout construction year), there were 3 reported accidents – 1 personal injury and 2 property damages. The probable cause of the accidents included failing to yield right-of-way and following too closely.

The morning and evening peak hour volumes, average vehicle stopped delay and level of service, by approaches, for the Towson Roundabout, the Annapolis Westgate Circle Roundabout and the Mount Rainier Roundabout, are presented for the “Before” roundabout and “After” roundabout periods in Tables 2, 4 and 6.

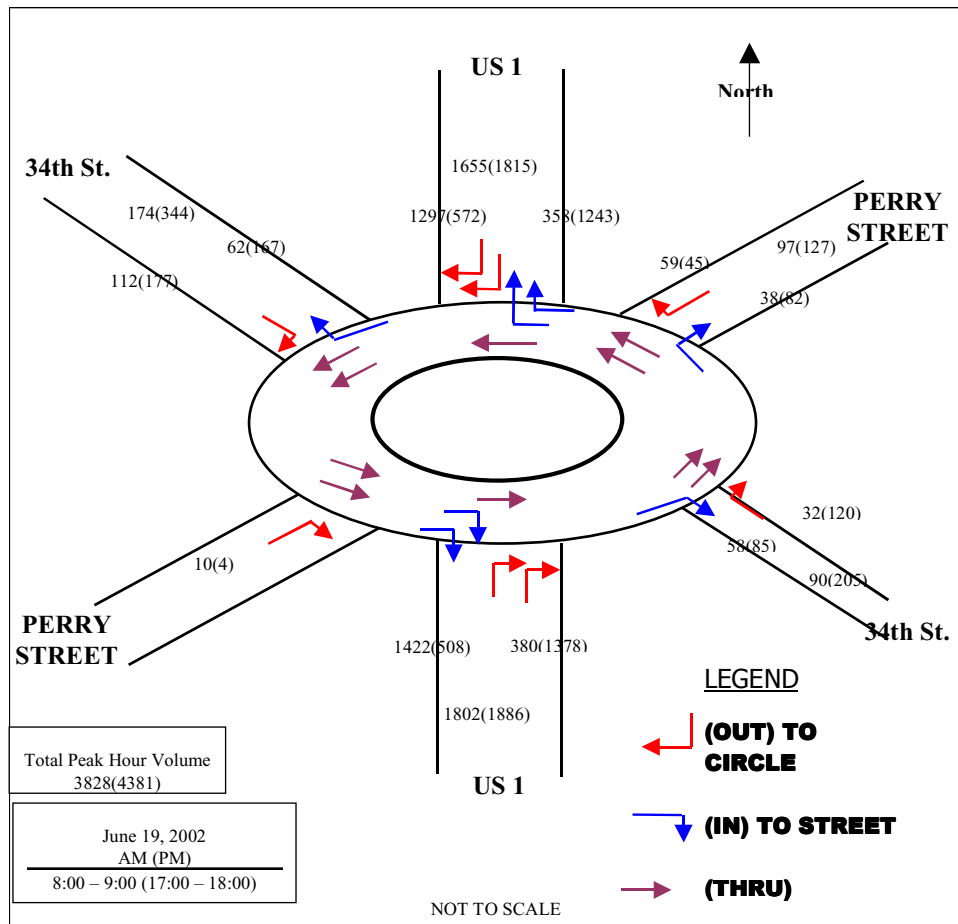


Figure 13B. “After” Lane Configuration Diagram of the Mount Rainier Roundabout, City of Mount Rainier

The Survey Results

Researchers on the modern roundabouts were focusing on the engineering aspects to optimize the roundabout’s design to address traffic operations and safety as well as traffic calming. However, research on the effectiveness of modern roundabouts in the context of urban areas is yet to be conducted.

In order to identify some qualitative benefits of the urban roundabouts, the researcher undertook a questionnaire survey. The questionnaire consisted of 10 general questions. Altogether 30 professionals from local and state governments and consultants - all from Maryland, were requested to participate in the survey. Only 13 professionals returned the completed questionnaires. Responses of these 13 completed questionnaires were tabulated and are presented in the Appendix 2. The results are summarized together as follows:

Principal problems of the signalized intersection (“Before” the roundabout). The respondents were asked to provide the principal problems faced by the signalized intersection prior to the roundabout installation. The answer to this question would provide the justification for the roundabout installation in the subject intersection.

Table 6. “Before” and “After” Peak Hour Volume, Average Delay and Level of Service for The Mount Rainier Roundabout, City of Mount Rainier

Particular	SB US 1		NB US 1		WB 34 th St.		EB 34 th St.		WB Perry St.		EB Perry St.		Total	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
"Before" - September 30, 1999 (Peak Hour: AM - 7:45 to 8:45; PM - 17:15 to 18:15)														
Peak Hour Volume (Entry Volume only)	1,415	606	343	1,439	32	45	184	220	159	55			2,133	2,365
Average Stopped Delay (Sec/Veh)	23	27	34	29	28	50	33	35	32	34			150	175
LOS	C	C	C	C	C	D	C	C	C	C				
"After" - June 19, 2002 (Peak Hour: AM 8:00 to 9:00; PM - 17:00 to 18:00)														
Peak Hour Volume (Entry Volume only)	1,297	572	380	1,378	32	120	112	177	94	45	10	4	1,925	2,296
Average Stopped Delay (Sec/Veh)	21	13	20	28	6	10	21	10	9	24	16	10	93	95
LOS	C	B	B	C	A	A	C	A	A	C	B	A		
Difference between "Before" and "After"														
Peak Hour Volume	-118	-34	37	-61	0	75	-72	-43	-65	-10	10	4	-208	-69
%	-8%	-6%	11%	-4%	0%	167%	-39%	-20%	-41%	-18%			-10%	-3%
Average Stopped Delay (Sec/Veh)	-2	-14	-14	-1	-22	-40	-12	-25	-23	-10	16	10	-57	-80
%	-9%	-52%	-41%	-3%	-79%	-80%	-36%	-71%	-72%	-29%			-38%	-46%

US 1 at 34th Street/Perry Street	Before (1995)*		After (2002)	
	AM	PM	AM	PM
LOS	C	C	A	A
V/C	0.805	0.784	0.494	0.447
Average Delay (Sec/Veh)			6.5	6

Source: Maryland State Highway Administration, Highway Information Services Division, 2002

The results showed that traffic congestion, poor aesthetic/urban design, poor geometric design and traffic accidents were the major problems in the signalized intersections prior to the construction of the roundabouts. Other problems included urban degradation, high maintenance cost and speeding vehicles. Therefore, there were traffic and non-traffic related problems at these signalized intersections, before their conversion to the modern roundabouts. See Table 7.

Table 7. The Survey Results - Primary Problems at the Signalized Intersections - “Before” Roundabout Construction

Original Intersection Problems	No. of Responses	%
Traffic congestion	11	25%
Poor aesthetic/urban design	11	25%
Poor geometric design	7	16%
Traffic accidents	6	14%
Urban degradation (crime)	4	9%
Speeding vehicle	4	9%
High maintenance cost	1	2%
Total	44	100%

Public Opposition and Acceptance to the Modern Roundabout. The Towson Roundabout faced public opposition since this was the first modern roundabout installed in a town center in the State of Maryland and possibly the first one in the United States. Respondents think that this public opposition has been overcome. The reasons that the public accepted the roundabout are higher capacity, improved urban design, (perceived) improved safety, and shorter delays compared to the signalized intersection. Other reasons included perceived lower maintenance cost, economic revitalization and traffic calming effect of the modern roundabouts. Respondents’ reported improved safety of the Towson Roundabout is contrary to the accident history discussed earlier. The accident history showed that the “After” roundabout accident rates increased significantly compared to the traffic signal, but the personal injury accidents decreased and at the same time, property damage accidents increased. These contradictory findings between the respondents and the historical accident data are due to the fact that survey respondents have perception that the Towson Roundabout is safer than the original intersection.

The concept of the Annapolis Westgate Circle Roundabout came originally from the community and so there was no public opposition. Their positive opinion of the roundabout has not changed yet.

There was strong support from the former Mayor of the City of Mount Rainier for the roundabout. There was, however, some public skepticism of the proposed roundabout. Due to public education, the public seems to be accepting the modern roundabout in the Mount Rainier intersection. Only time will tell whether the public perceived benefits would be realized such as improved aesthetic, traffic calming and economic

Public Education. Prior to the installation of the Towson Roundabout, Baltimore County, MD SHA and Towson Business Association undertook a major public education program to educate the public about the benefits of urban roundabouts. They implemented community relation works as well as media campaign highlights.

The City of Annapolis launched a limited public education program via advertisement and public information meetings. The elected officials strongly supported the roundabout since it improved traffic operations and helped to revitalize the town center.

The City of Mount Rainier provided information to the public through information meetings and brochures.

Overall Impacts of the Roundabout. The respondents were asked to answer the overall impacts of the roundabout on the traffic operation and safety, as well as urban revitalization issues. The researcher was interested to document these impacts of the urban roundabouts.

Overall the modern roundabouts have significant impact on urban revitalization issues like aesthetic/urban design (24 percent), economic development (17 percent) and traffic calming (9 percent), as well as, on traffic operations and safety issues like shorter delays (19 percent), higher capacity (19 percent) and improved safety (10 percent) in urban areas. See Table 8.

Benefits of Urban Roundabouts versus Traffic Signals. Compared to the “Before” the roundabout, the aesthetic/urban design, economic development and desired vehicle speed improved in the “After” roundabout. Other improvements include the reduced vehicle delay, higher capacity and pedestrian movement.

Table 8. The Survey Results - Overall Impacts of Urban Roundabouts “After” Roundabout Construction

Criteria	Total Number of Responses	%
Aesthetic /urban design improvement	14	24%
Shorter delays	11	19%
Higher capacity	11	19%
Economic revitalization	10	17%
Improved safety	6	10%
Traffic Calming	5	9%
Lower maintenance cost	2	3%
Total	59	100%

Seventy-eight percent of the respondents reported that the roundabout improved the criteria under study. Only 13 percent reported the criteria worsened. The most important criteria the roundabout improved were aesthetic (19 percent), followed by economic development (12 percent), pedestrian movement (15 percent) and lowered vehicle speed (14 percent). The respondents also reported that there was improvement in delay, capacity and safety as well. See Table 9.

Table 9. The Survey Results - “After” Roundabout General Impacts

Criteria	Total Number of Responses			% Improved
	Improved	Worse	Same	
Aesthetic	14			19%
Economic Development	11			15%
Desired Vehicle Speeds	10		1	14%
Vehicle delay	9			12%
Capacity	9		1	12%
Safety	7	2	4	10%
Pedestrian Movement	7	3	1	10%
Bike Movement	3	2	3	4%
Maintenance Cost	2	4	3	3%
Total	72	12	8	72
%	78%	13%	9%	100%

There were mixed perception about some criteria like traffic safety, bike and pedestrian movement, and maintenance cost. Some responded these criteria were the same or even worsened after the installation of the roundabout. Of these, the most important criteria include the pedestrian movement particularly the disabled persons (blind) and the maintenance cost. Pedestrian crossing seems to be a major issue for the opponents of the modern roundabout. The basic concept of continuous flow of traffic with the provision of yield to pedestrians is perceived as unsafe since some drivers do not stop for pedestrians. Also, some of the roundabouts like the Towson Roundabout are oval and thus enables the drivers to speed up – thus making it less safe for pedestrian crossing. This is a matter of public education for both pedestrians and drivers and enforcement of the driving rules at the roundabout. Additionally, the design of the roundabouts should be modified so that it considers pedestrian safety.

Another important issue is the maintenance cost. Experts argue that the roundabout is cheaper to maintain than the traffic signal. However, some local government professionals argue that the roundabout is more expensive to maintain than the traffic signal. They seem to include cost of maintaining the landscaping, aesthetics, lighting, etc. in their maintenance cost. The experts, on the other hand, say that those are additional costs and should not be included in the maintenance cost of the roundabout while comparing it with the traffic signal.

In the urban areas, the construction of modern roundabout should be accompanied with landscaping, lighting, benches, irrigation, pruning, etc. This increases the cost of construction and maintenance.

Beautification Effect of the Roundabout. Respondents believe that the modern roundabout enhanced the beauty of the town. For example, one respondent said that “*Yes, by placing the roundabout and cleaning*

up this five-legged intersection, it became a centerpiece for the York Road Revitalization Project tying the Towson Mall with their older business district along York Road.”

Economic Revitalization Effect of the Roundabout. Almost all respondents reported that the roundabouts have helped revitalization efforts. After the construction of the roundabout, new businesses have been established or are planning to come into the area; the existing businesses are remodeled and expanded. The roundabout seem to have helped in the town’s revitalization efforts by slowing the traffic, encouraging pedestrian movement, improving the attractiveness of the area and making it a focal point. People started visiting the area for food and drinks, recreation, and shopping. Offices and other businesses were attracted to the town where activities were bustling. This had the economic agglomeration effect.

Baltimore County’s Economic Development Director Bob Hanna said that the whole block between the Towson Roundabout and Virginia Avenue is being planned for revitalization. The old Hutzlers Department store building was revitalized – which sat vacant for nearly 15 years. These are the direct result of the roundabout, Mr. Hanna added.

Similarly, the developer improved some of the vacant or under utilized buildings near the Annapolis Westgate Circle Roundabout. The City of Annapolis has received applications for hotels, office and parking development along the Inner West Circle Corridor (MD 450 from the roundabout to Church Circle).

The City of Mount Rainier’s primary objective of the roundabout construction was to revitalize the town center. The roundabout is a component of the overall revitalization efforts. The City wants to develop arts district on the south-east quadrant of the roundabout- along the northbound US 1. MD SHA is developing a concept plan for the streetscape project for the US 1 corridor from the roundabout to Eastern Avenue.

Major Problems and Disadvantages of the Urban Roundabouts. Following are the major problems and disadvantages of the urban roundabouts:

- Acceptance by the motorists and pedestrians of the roundabout from conventional intersection.
- Perceived pedestrian crossing/safety issues.
- Significant challenges for the visually impaired pedestrians to traverse the roundabout.
- Higher construction and maintenance costs.
- Roundabouts do not have pedestrian activated signals to give exclusive walk phases for pedestrians.
- Traffic volumes are too high for commercial revitalization. One of the respondents opined that the traffic volume in the Towson Roundabout was very high. Due to the high traffic volume, there was a continuous flow of uninterrupted traffic flow. This limited the pedestrian movement around the roundabout – thus, adversely impacting the revitalization efforts. This opinion was not heard from any other sources.
- Oval shape encourages higher speeds in roundabout.
- Disruption to traffic flow in a corridor. Some respondents reported that modern roundabouts disrupts the traffic platooning in a corridor. Generally, traffic signals are coordinated along the corridor to enable a continuous traffic flow, which is called “platooning effect”. By installing a modern

roundabout in an intersection along the corridor, the platooning effect is disrupted. A gap would be developed between two traffic “platoons”.

- Traffic moves efficiently and pedestrians have difficulty crossing. This is because drivers don’t yield to the pedestrians.

Lessons Learned from the Urban Roundabouts. The respondents were asked to identify the lessons learned from the urban roundabouts. Their responses are given below.

(a) Roundabout Design: Entry and exit geometry are critical to the safety of the roundabout. Build roundabouts as circular as possible. Do not create long tangent solutions such as Towson since it leads to speed differentials and, therefore, increases accidents. Roundabouts function best when they are round and not oval shaped. More needs to be done to calm (slow down) the traffic

(b) Public Involvement: Involve the community early in the process and get their input in the process. Public involvement is critical and essential in making it work.

(c) Drivers and Pedestrians/Bicyclists Education: The government needs to educate drivers, pedestrians and bicyclists on how to traverse roundabouts. It needs to enforce the traffic operation rules in the roundabout area for initial years of the construction.

(d) State Law: The government needs to address roundabouts in the state vehicle laws.

(e) Pedestrian Safety: Pedestrian friendliness should be a primary goal for an urban roundabout. Driver education is important and should emphasize pedestrian safety. An expert in design for pedestrians should be involved in design from the beginning.

(f) Economic Revitalization: An urban roundabout helps to revitalize the depressed areas.

(g) Aesthetic/Urban Design Improvement: An urban roundabout enhances the aesthetics of the area and becomes part of the better urban design.

(h) Traffic Operations and Safety: An urban roundabout significantly improves traffic operations by reducing stopped vehicle delays and reduces severe injury accidents.

(i) Others: Modern roundabouts can help alleviate congestion and reduce severe accidents, as well as, revitalize depressed urban areas; however, they are by design, unfriendly to the pedestrians.

SUMMARY OF FINDINGS

The primary objective of this study was to document the benefits of three urban roundabouts from the State of Maryland by using the “Before” and “After” data. The benefits of a modern roundabout in an urban area were classified into two – traffic operation and safety related and the urban revitalization related benefits. Data for the traffic operation and safety related benefits included the peak hour traffic volume, delay, LOS, and traffic accidents. These data were obtained from the MD SHA for the “Before” roundabout condition. The 1999 counts and delay study was used for the “After” Towson Roundabout. New peak hour volume counts and delay study was conducted in June 2002, for the “After” roundabout for the Annapolis Westgate Circle Roundabout and the Mount Rainier Roundabout by MD SHA.

The urban revitalization related benefits of urban roundabouts include general background of the urban roundabouts and the effect of the roundabout on economic development, traffic calming, aesthetics and

urban design. No quantitative data were available on these benefits. These were, therefore, collected by conducting a questionnaire survey with selected local and state government professionals and consultants.

The findings are summarized below:

Traffic Volumes

Compared to the “Before” roundabout, the “After” roundabout peak hour throughput traffic volumes slightly decreased or increased. For example, the “throughput” volume increased 10 percent and 26 percent in the morning and evening peak hours, respectively, in the Annapolis Westgate Circle Roundabout. However, in the Mount Rainier Roundabout, the peak hour throughput volume decreased 7 percent and 10 percent in the morning and evening, respectively. The traffic throughput volume decreased 7 percent in the morning and increased 2 percent in the evening in the Towson Roundabout. The mixed results in the peak hour throughput volume in this study may be attributed to two factors. First, the presence of alternate routes nearby the roundabout may lead to a decline in the peak hour traffic throughput volumes at the initial years of the roundabout development.

The second factor that is related to the first factor, is the driver’s behavior in the initial years of the roundabout operation. Some drivers may likely avoid roundabouts by taking another route. However, this is a temporary situation. Once the drivers are fully educated and comfortable, they will start driving through the roundabout. This was the case in the Mount Rainier and Towson roundabouts. For example, Towson Bypass is an alternate route to MD 45. Similarly, drivers can use local roads to bypass the Mount Rainier Roundabout. No alternate east-west routes are available to bypass the Annapolis roundabout.

The selected three urban roundabouts do not give clear patterns regarding the effect of the roundabouts on the peak hour throughput volumes. Also, these results may have been influenced by the daily and seasonal variations.

Vehicle Delay and Level of Service

The “After” roundabout average vehicle stopped delay was less than 30 seconds per vehicle on all approaches in the Towson Roundabout and Mount Rainier Roundabout, while this was just 15 seconds per vehicle for the Annapolis Westgate Circle Roundabout. The average vehicle stopped delay decreased consistently on both morning and evening peak hours by 54 percent and 40 percent, respectively, for the Towson Roundabout; by 93 percent and 90 percent, respectively, for the Annapolis Westgate Circle Roundabout, and by 38 percent and 46 percent, respectively, for the Mount Rainier Roundabout. The delay decreased significantly for all approaches – ranging from 7 percent to 91 percent for the Towson Roundabout, 50 percent to 96 percent for the Annapolis Gateway Circle Roundabout and 3 percent to 80 percent for the Mount Rainier Roundabout.

The LOS for the Towson Roundabout, during the morning peak hour, improved at least one level at all approaches. During the evening peak hours, the LOS improved 3 levels to LOS “A” for the southbound MD 146 approach and 2 levels to LOS “C” for the eastbound Joppa Road approach.

For the Annapolis Westgate Circle Roundabout, the LOS of the approaches were “A” during the morning and evening peak hour in the “After” roundabout, except eastbound MD 450 during the evening peak hour where the LOS was “B”. Most of these approaches were operating at LOS of “D” during both morning and evening peak hours in the “Before” roundabout.

The LOS for most approaches was improved in the Mount Rainier Roundabout from LOS “C” to LOS “A”.

These findings clearly indicate that these urban roundabouts significantly reduced the vehicle delays and improved the traffic operation. However, the readers are advised that these results may have been due to the daily and seasonal variations. The researcher did not consider these variations in his analysis.

Traffic Safety

Improved safety is one of the primary benefits of the modern roundabouts over traffic signals. However, the safety results of the Towson Roundabout are mixed. Compared to the “Before” roundabout, the average number of accidents per year increased by 160 percent in the “After” roundabout. The average number of personal injury accidents decreased 69 percent, while property damage accidents increased by 527 percent. The increased accidents included fender bender, requiring vehicle repairs. The accident rate in 2000 at the Towson Roundabout was statistically significant indicating that this rate is higher than similar other State maintained roadways. The higher accident rate at this roundabout may be attributable to the oval shaped roundabout and the drivers’ unfamiliarity of driving in the circle. Generally, experts say that a circular roundabout is better for safety purpose than the oval roundabouts. This could be attributed to the speed inconsistencies that an oval roundabout presents. Although the Towson Roundabout has been in existence little over four years, it seems that drivers are still confused about driving around the circle.

The Annapolis Gateway Circle Roundabout has been successful to address the traffic safety issues. Compared to the “Before” roundabout, the average number of accidents decreased by 58 percent. Both personal injury and property damage accidents decreased significantly.

The Mount Rainier Roundabout was opened in February 2002 and therefore no “after” roundabout accident data were available to report at this time. There were no police reported accidents in 1998, 1999 and 2000 – the years for the “Before” roundabout.

From the above findings on the traffic safety benefits of the urban roundabouts, an oval urban roundabout is less safer than a circular roundabout. Alternatively, a circular roundabout is more preferable to a oval roundabout for improved traffic safety.

Urban Revitalization

The researcher conducted a questionnaire survey with 13 local and state government officials, and consultants – all from Maryland. They were asked to answer 10 general, qualitative questions related to various aspects of urban revitalization. One of the primary goals of these three selected urban roundabouts was to revitalize the business areas near to the roundabouts. The purpose of the survey was to evaluate whether or not these roundabouts were successful in achieving the revitalization goal. The survey results are summarized below.

General

Public education was provided through information meetings, media campaigns, brochures and community relations to a lesser degree for the Annapolis Westgate Circle Roundabout and Mount Rainier Roundabout and to a significantly higher degree for the Towson Roundabout.

Being the first urban roundabout in the State of Maryland and possibly the first in the United States, the Towson Roundabout met significant public opposition. However, the Annapolis Westgate Circle Roundabout and the Mount Rainier Roundabout faced little or no public opposition to their construction. Whenever public opposed the roundabout installation; benefits of roundabouts such as higher capacity, improved urban design, (perceived) improved safety, shorter delays, lower maintenance cost, economic revitalization and traffic calming effect may changed the public’s opinion in favor of the roundabout, particularly for the Towson and Annapolis Westgate Circle Roundabouts.

Principal problems of the signalized intersection (“Before” the roundabout) were traffic related (traffic congestion, poor geometric design and traffic accidents) and urban revitalization related (poor aesthetic/urban design, traffic calming and urban degradation.)

Overall the modern roundabouts have had a significant impact on traffic operations (shorter delays and higher capacity), economic revitalization and aesthetic/urban design in urban areas. Better safety (injury accidents) and traffic calming are other impacts of the roundabouts.

Benefits of Urban Roundabouts versus Traffic Signals

The respondents were asked to specify the benefits of urban roundabouts over the traffic signals. The researcher was interested to document the benefits of urban roundabouts from the survey. The following are the summary of the survey results.

Compared to the “Before” the roundabout, the aesthetic/urban design, economic development and desired vehicle speed improved in the “After” roundabout. Other improvements included reduced vehicle delay and higher capacity. In addition, the respondents reported that the roundabouts helped pedestrian movements since there was a slow moving traffic, and splitter islands acted as a refuge area. However, some citizens and professionals disputed this fact.

There were mixed perception about some criteria like traffic safety, bike and pedestrian movement, and maintenance cost. Contrary to experts’ view, the respondents argued that the roundabout is more expensive to maintain than the traffic signal. They seem to include cost of maintaining the landscaping, aesthetics, snow removal, lighting, etc. in their maintenance cost.

Respondents believe that the modern roundabout enhanced the beauty of the town.

Respondents reported that the roundabouts have helped revitalization efforts. The roundabout seemed to have helped in the town’s revitalization efforts by slowing the traffic, encouraging pedestrian movement, improving the attractiveness of the area and making it a focal point for the town. People started visiting the area for food and drinks, recreation, and shopping. Businesses were attracted to the town where activities were bustling. This had the economic agglomeration effect.

Lessons Learned from the Urban Roundabouts

The respondents were asked to identify the lessons that were learned in these selected roundabouts. The purpose of this question was to document experiences that could be applied elsewhere. The responses are summarized below.

Roundabout Design.

Entry and exit geometry are critical to the safety of the roundabout.

Build roundabouts as circular as possible.

Public Involvement.

Involve the community early in the process and get their input continually throughout the process.

Public involvement is critical and essential in making it work.

Drivers and Pedestrians/Bicyclists Education.

Educate drivers, pedestrians and bicyclists on how to pass through roundabouts. We need to include driving rules in the driver's manual. (Note: This is being done this summer in the updated Drivers Handbook.)

We need to also enforce the traffic operation rules in the roundabout area for initial years of the construction.

Pedestrian Safety.

Pedestrian friendliness should be a primary goal for an urban roundabout. Pedestrian safety should be emphasized in drivers' education. An expert in design for pedestrians should be involved in design from the beginning.

Economic Revitalization.

An urban roundabout helps to revitalize the depressed areas.

Aesthetic/Urban Design Improvement.

An urban roundabout enhances the aesthetics of the area and becomes part of the better urban design.

Traffic Operations and Safety.

An urban roundabout significantly improves traffic operations by reducing stopped vehicle delays and reduces severe injury crashes eliminating right angle ("T" bone) and head on accidents.

Others.

Improvement of aesthetics does not always result in a greater pedestrian safety.

Modern roundabouts can help alleviate congestion and reduce severe crashes, as well as revitalize depressed urban areas; however, they are, by design, unfriendly to the pedestrians, particularly the disabled persons such as the vision impaired.

APPLICATIONS OF THE STUDY FINDINGS

The study findings clearly showed that these urban roundabouts had traffic operation benefits. These roundabouts significantly reduced vehicle stop delays, thereby improving the traffic operations and reducing auto related air pollution. Another important finding was that these roundabouts significantly reduced personal injury accidents. However, the number of accidents increased significantly in the "After" roundabout in the Towson Roundabout. The non-severe accidents like sideswipes increased significantly. From the traffic safety perspectives, a circular urban roundabout is preferable than an oval urban roundabout.

The improved traffic operation and reduced injury accident benefits are the primary advantages of the modern roundabouts over the conventional signalized intersections. These findings are consistent with earlier studies.

As indicated by the questionnaire survey, these roundabouts have played a positive role enhancing the economic revitalization of the town center. New businesses have already come to the area or are planning to come to the area as a direct result of these roundabouts (23). The urban roundabouts, with landscaping and streetscaping treatments, have become a focal point in the town and businesses and people are attracted to the area nearby the roundabouts.

The data on the role of the roundabouts in the overall accident reduction was unclear. Another inconclusive issue in this study was the effect of the roundabouts on the traffic volumes. Due to the data and time constraints, the researcher could not examine several issues, including cost-benefit analysis and role of the urban roundabout on the economic development. The inconclusive and untouched issues should be further studied. – so that these roundabouts' full impact could be evaluated. Also, due to the complex nature of urban centers, additional studies on design features should be conducted so that issues like pedestrian/bicyclist crossing, crossing features for the visually impaired persons, right-of-way, etc., are well accommodated.

As indicated by this study, modern roundabouts have traffic operation and safety benefits as well as urban revitalization potential for urban areas. Modern roundabouts should be introduced to many suitable urban locations in the State of Maryland as a tool for addressing traffic congestion as well as urban revitalization.

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23. Please contact Mr. Bob Hannon, Director, Baltimore county Department of Economic Development, for Towson Roundabout at 410-887-8000, Mr. Dirk Geratz, Senior Planner, City of Annapolis Department of Planning and Zoning at 410-263-7961, and Ms. Dineene O'Connor, Senior Planner, Maryland – National Capital Park and Planning Commission, for Mount Rainier Roundabout at 301-952-3573.

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NOTE: Names of the contact persons, who participated in the survey interview, are in bold.

APPENDIX B. SUMMARY TABLES OF QUESTIONNAIRE SURVEY RESPONSES

**Table A. Benefits of Urban Roundabouts in the State of Maryland
Survey Questionnaire Results**

Primary problems of the original, signalized intersection at this location – before construction of the modern roundabout.

Original Intersection Problems	Towson Roundabout	Annapolis Westgate Circle Roundabout	Mount Rainier Roundabout	Total
a. Traffic accidents - motorists	2		1	3
b. Traffic accidents – pedestrians/bicyclists	2		1	3
c. Traffic congestion	6	5		11
d. Poor geometric design	4	2	1	7
e. High maintenance cost			1	1
f. Speeding vehicle	1		3	4
g. Poor aesthetic/urban design	4	4	3	11
h. Urban degradation (crime)	1	2	1	4
i. Other				
Total	20	13	11	44

**Table B. Benefits of Urban Roundabouts in the State of Maryland
Survey Questionnaire Results**

Did the roundabout initially meet with the public opposition? If yes, has the public opinion changed over time?

Roundabouts	Public Opposition Yes	Public Opposition Changed
Towson	5	6
Annapolis	0	0
Mt. Rainier	3	Too early to say.

If yes, state the most important factors that led to the public's acceptance of the roundabout.

Public's Acceptance Factors	Towson Roundabout	Annapolis Westgate Circle Roundabout	Mount Rainier Roundabout	Remarks
a. Better Safety	2		1	
b. Shorter Delays	2			
c. Higher Capacity	3			
d. Lower Maintenance Cost	1			
e. Aesthetic/Urban Design Improvement	3		2	
f. Traffic Calming	1		2	
g. Economic Revitalization	1		1	
h. Other*				
Total	13		6	

*The Annapolis Westgate Circle Roundabout: The community was behind the idea of a roundabout from the beginning and this opinion has not changed.

**Table C. Benefits of Urban Roundabouts in the State of Maryland
Survey Questionnaire Results**

Did you undertake any special public education efforts before undertaking the roundabout? Please explain.

Roundabouts	Public Education prior to Roundabout Installation (Yes)	What kind?
Towson	4	<p>Yes, the County Office of Community Revitalization and the Towson Business Association developed an extensive community relations and media campaign. Community Relations: Ongoing meetings and written progress updates coordinated with elected officials. Public, business and community association meetings were held to keep citizens informed of construction activities. Brochures, project newsletters and fliers highlighting project descriptions, schedules and detours were distributed to businesses, shopping malls, the local library and other county offices, schools, community associations and residents. Public speaking engagements were scheduled for interested groups, such as the elderly, and the disability community to address specific concerns. A “Towson Enhancement Project” page on the internet.</p> <p>Media Campaign Highlights: Project press conference.</p> <p>Press releases on project updates. Ongoing communication with traffic reporters. Pitching special interest stories to local newspapers.</p>
Annapolis	Yes, on a limited scale.	<p>Some advertisement and public info meetings. Local papers informed the public of the project and an articles was written about how to use the circle.</p> <p>The City staff did some public outreach. Elected officials strongly supported the project since it improved traffic operations while enhancing economic activities from the West Street approach to the state house.</p>
Mt. Rainier	Not really.	Public informational meetings and brochures. Some newspaper articles and info dissemination through the project task force.

**Table D. Benefits of Urban Roundabouts in the State of Maryland
Survey Questionnaire Results**

In comparison to the previous signalized intersection, what have been the general impacts of the roundabout relative to the following criteria:

Criteria	Towson Roundabout	Annapolis Westgate Circle Roundabout	Mount Rainier Roundabout	Total
a. Better safety	3	2	1	6
b. Shorter delays	5	5	1	11
c. Higher capacity	4	5	2	11
d. Lower maintenance cost	1	1		2
e. Aesthetic /urban design improvement	6	5	3	14
f. Traffic Calming	3	1	1	5
g. Economic revitalization	4	4	2	10
h. Other				
Total	26	23	9	59

**Table E. Benefits of Urban Roundabouts in the State of Maryland
Survey Questionnaire Results**

In comparison to the previous signalized intersection, what have been the general impacts of the roundabout relative to the following criteria:

Criteria	Towson Roundabout			Annapolis Westgate Circle Roundabout			Mount Rainier Roundabout			Total		
	Improved	Worse	Same	Improved	Worse	Same	Improved	Worse	Same	Improved	Worse	Same
a. Safety	3	2		4			Too soon to tell.			7	2	4
b. Vehicle delay	4			4			1			9		
c. Capacity	4		1	4			1			9		1
d. Desired Vehicle Speeds	4	1		5			1			10		1
e. Pedestrian Movement	4	2		2	1	1	1			7	3	1
f. Bike Movement	1	2	1	2		1			1	3	2	3
g. Maintenance Cost	2	1	1		2	2		1		2	4	3
h. Aesthetic	6			5			3			14		
i. Economic Development	6			4			1			11		
j. Other												
Total	34	8	3	30	3	4	8	1	1	72	12	8

**Table F. Benefits of Urban Roundabouts in the State of Maryland
Survey Questionnaire Results**

Do you think that the modern roundabout enhanced the beauty of the town? Please explain.

Roundabout	Did the modern roundabout enhance the town's beauty? (Yes)	Comments
Towson	4	<ul style="list-style-type: none"> • Yes, big improvement. • Yes, by placing the roundabout and cleaning up this five legged intersection, it became a centerpiece for the York Road Revitalization Project tying the Towson Mall with the older business district along York Road. • Yes. The roundabout helped to organize a previously chaotic space and provided a focal point for plantings. • Yes. The area around the signal was unattractive... in terms of uses and visual appearances. The circle, when the center is maintained is quite nice. It also gives a location identity to the area. • No opinion.
Annapolis	5	<ul style="list-style-type: none"> • Yes. A lot of money and effort were put into the project to improve the aesthetics. • Yes, Major urban design victory for the community. • Yes. This was a very depressed area of Annapolis that was in need of Urban Redesign.
Mt. Rainier	3	<ul style="list-style-type: none"> • Yes, significant effort to improve the image of the town through the project. Allocated a budget for public art-work. Primary purpose of the project – to enhance the beauty of the town, but there are some traffic operational benefits anticipated. • Absolutely, this area was very depressed and rundown. With the roundabout and accompanying streetscape the area looks much better. • Yes, the lighting, sidewalk and the roundabout itself diminish the dominance of asphalt at the intersection of Perry Street, 34th Street and Rhode Island Avenue.

**Table G. Benefits of Urban Roundabouts in the State of Maryland
Survey Questionnaire Results**

Do you think that the modern roundabout helped in revitalization of the area? Please explain.

Roundabout	Did the modern roundabout help in revitalization of the area? (Yes)	Comments
Towson	5	<ul style="list-style-type: none"> • Yes, led to about \$30 million investment. • Absolutely. The old Hutzlers Department store building, which sits in the NE quadrant sat vacant for approx. 15 years and the owner has stated that he would not redevelop the building until we (SHA/the County) did something with the intersection. Hence the building (where Barnes & Noble book store is) is now called “The Traffic Circle”. • Yes. The roundabout and streetscape improvements encouraged private investment in the vicinity of the improvements. • Yes. The circle has improved real estate values in the area. It cleared up a terrible point of congestion. It gave the area a location identity. Many businesses such as redevelopment of the former Hutzler’s Department Store and improvement of the existing businesses such as the Souri’s Restaurant have been possible due to the roundabout. Also, new development such as the proposed Bahama Breeze theme restaurant is planned for construction on top of the small deck right at the Joppa Road entrance to Towson Circle’s lower level parking. However, due to other reasons, the Investment Building and a small parcel near the roundabout are currently vacant.
Annapolis	5	<ul style="list-style-type: none"> • Yes. Several major building projects are under design. • Yes, several new buildings are under construction or have been recently completed. The property owners are renovating their buildings. This project spurred the economic development. • Yes. In recent travels through the area there is obvious redevelopment occurring in this area.

Mt. Rainier	3	<ul style="list-style-type: none">• Probably too soon to tell, however, there is already some application for an apartment complex nearby the roundabout. There have been some additional economic activities there. Streetscape improvements alone cannot accomplish revitalization. However, when there is a local revitalization spearheaded by an organization such as the Gateway Community Development Corporation, each initiative such as the roundabout become the pieces of a greater effort and contributes to an overall revitalization. The key however is not any one project but the continuous pursuit of revitalization, which depends on the organization and people/community commitment.
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**Table H. Benefits of Urban Roundabouts in the State of Maryland
Survey Questionnaire Results**

What are the major problems and disadvantages of the urban roundabouts? Please list them. Responses for the three roundabouts are combined.

Major Problems and Disadvantages of Urban Roundabouts
<p><i>a. Acceptance by the motorists and pedestrians of the roundabout from the conventional intersection</i></p> <ul style="list-style-type: none"> • Driver confusion ... particularly new drivers to the area. Although once they get used to the roundabout I believe they are really quite simple.
<p><i>b. Perceived pedestrian crossing/safety.</i></p> <ul style="list-style-type: none"> • Pedestrian crossing. Once higher pedestrian volume occurs, it will have to be signalized. Back to square one. • The design is raised up and blocks line of sight by pedestrians to see traffic and vice-versa. (Mt. Rainier) • Roundabouts do not have pedestrian activated signals to give exclusive walk phases for pedestrians. • No traffic signals to stop traffic for pedestrian crossings; • Traffic moves efficiently and pedestrians have difficulty crossing. This is because drivers don't yield to the pedestrians.
<p><i>c. Significant challenges for the visually impaired pedestrians</i></p> <ul style="list-style-type: none"> • The blind community does not like roundabouts because they depend on their sense of hearing to cross intersections and with the roundabout, in theory, traffic never stops. Roundabouts are not friendly for the handicapped, particularly the vision impaired community. • Navigating the roundabout by the disabled person around the new configuration.
<p><i>d. Geometry of the roundabout</i></p> <ul style="list-style-type: none"> • Oval shape encourages higher speeds in roundabout;
<p><i>e. Costly</i></p> <ul style="list-style-type: none"> • Too costly – over \$8 million for construction (Annapolis Roundabout) • Higher maintenance cost
<p><i>f. Other</i></p> <ul style="list-style-type: none"> • Traffic volumes are too high for commercial revitalization.

**Table I. Benefits of Urban Roundabouts in the State of Maryland
Survey Questionnaire Results**

What are the lessons learned from this urban roundabout project? Please explain.

Lessons learned
<p><i>a. Roundabout Design</i></p> <ul style="list-style-type: none"> • Entry and exit geometry are critical to the safety of the roundabout. • Build roundabouts as circular as possible. Do not create long tangent solutions such as Towson since it leads to speed differentials and, therefore, increases crashes. • Roundabout's function best when they are round and not oval shaped. • More needs to be done to calm (slow down) the traffic.
<p><i>b. Public Involvement</i></p> <ul style="list-style-type: none"> • Involve the community early in the process and get their input in the process. • Public involvement is critical and essential in making it work.
<p><i>c. Drivers and Pedestrians/Bicyclists Education</i></p> <ul style="list-style-type: none"> • We need to educate drivers, pedestrians and bicyclists on how to pass through roundabouts. • We need to include driving rules in the driver's manual. • We need to enforce the traffic operation rules in the roundabout area for initial years of the construction.
<p><i>d. State Law</i></p> <ul style="list-style-type: none"> • We need to address roundabouts in the state vehicle laws.
<p><i>e. Pedestrian Safety</i></p> <ul style="list-style-type: none"> • Pedestrian friendliness should be a primary goal for an urban roundabout; • Driver education is important and should emphasize pedestrian safety; • An expert in design for pedestrians should be involved in design from the beginning.
<p><i>f. Economic Revitalization</i></p> <ul style="list-style-type: none"> • An urban roundabout helps to revitalize the depressed areas.

g. Aesthetic/Urban Design Improvement

- An urban roundabout enhances the aesthetics of the area and becomes the part of the better urban design.

h. Traffic Operations and Safety

- An urban roundabout significantly improves the traffic operations by reducing stopped vehicle delays and reduces severe injury crashes.

Issues

- Modern roundabouts can help alleviate congestion and reduce severe crashes, as well as revitalize depressed urban areas; however, they are, by design, unfriendly to the pedestrians, particularly the disabled persons like blind persons.
- Improvement of aesthetics does not always result in a greater pedestrian safety.

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