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16. Abstract This document is the culmination of the ninth offering of an innovative transportation engineering graduate course at Texas A&M University entitled, "Advanced Surface Transportation Systems". The ninth offering of the course was presented during the summer 1999 term. As part of the course, a Mentors Program provides students with unique learning experiences. Six top-level transportation professionals from private enterprise and departments of transportation, who are leaders in their field and who have extensive experience with Intelligent Transportation Systems, were invited to Texas A&M University to present a 1½-day Symposium on Advanced Surface Transportation Systems at the beginning of the summer term. Immediately following the Symposium, the students enrolled in the course participated in a Forum and a Workshop with the transportation professionals and course instructor. Each student had discussions with the transportation professionals and the course instructor to identify a topic area for a term paper. Based on mutual interests, each student was assigned to one of the professionals who served as a mentor (along with the course instructor) for the remainder of the summer term. Each student worked with his/her mentor and course instructor to identify a topic area and objectives for a term paper. In addition to discussions with the course instructor, the students (communicating via telephone, fax, e-mail, and mail) worked directly with the mentors throughout the term while preparing their term papers. The mentors returned to the Texas A&M University campus near the end of the summer term to hear and critique the students' presentations.					
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**COMPENDIUM:
GRADUATE STUDENT PAPERS ON
ADVANCED SURFACE TRANSPORTATION SYSTEMS
AUGUST 1999**



Class Instructor and mentors (front row, from left) Conrad Dudek, Carol Zimmerman, Wayne Kittelson, Partrick Irwin; (back row) Thomas Hicks, H. Douglas Robertson, William Spreitzer

PREFACE

This document is the culmination of the ninth offering of an innovative transportation engineering graduate course at Texas A&M University entitled, "Advanced Surface Transportation Systems," which was presented during the 1999 summer term. As part of the course, a Mentors Program provided the students with unique learning experiences. 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 at the beginning of the summer term. Immediately following the Symposium, the students enrolled in the course participated in a Forum and a Workshop with the transportation professionals and course instructor. Each student held numerous discussions with the transportation professionals and course instructor to identify a topic area for a term paper. Based on mutual interests, each student was assigned to one of the professionals who served as a mentor (along with the course instructor) for the remainder of the summer term. Each student worked with his/her mentor and course instructor to identify a topic area and objectives for a term paper. In addition to discussions with the course instructor, the students (communicating via telephone, e-mail, fax and mail) worked directly with the mentors throughout the term while preparing their term papers. The mentors returned to the Texas A&M University campus near the end of the summer term to hear and critique the students' presentations.

One important objective of the program was to develop rapport between the students and the transportation professionals. The opportunity for the students to communicate and interact with top transportation officials, who are recognized for their knowledge and significant contributions both nationally and internationally, was a key element to the students gaining 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.

Thomas Hicks, Patrick Irwin, Wayne Kittelson, H. Douglas Robertson, William Spreitzer and Carol Zimmerman devoted considerable time and energy to this program. We are extremely grateful for their valuable contributions to the educational program at Texas A&M University.

The opportunity to bring top-level transportation professionals to the campus was made possible through financial support provided by the "Advanced Institute" at Texas A&M University which is sponsored by the University Transportation Centers Program of the U.S. Department of Transportation, and from funds received from the Zachry Teaching Program from the College of Engineering at Texas A&M University.

Sherry Burr and Elizabeth Post, Senior Secretaries with the Texas Transportation Institute, coordinated the Symposium and Workshop in a very efficient and professional manner.



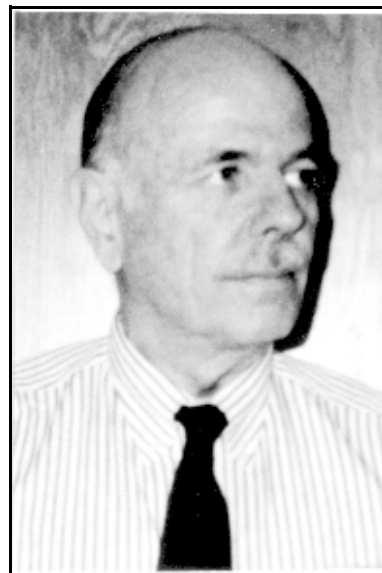
Congratulations are extended to the transportation engineering graduate students who participated in this course. Their papers are presented in this Compendium. Appendix A and B show the transportation professionals who graciously served as mentors in previous years and the students who participated in the Advanced Institute Program since 1991. A listing of all the papers that were prepared since the first offering of the course in 1991 is shown in Appendix C of this Compendium.

Conrad L. Dudek
Professor of Civil Engineering & Associate Director, SWUTC

1999 MENTORS

THOMAS HICKS

Thomas Hicks is presently the Director of the Office of Traffic & Safety for the Maryland State Highway Administration, one of six engineering offices reporting to the Chief Engineer. He is responsible for coordinating the work of six Divisions - Traffic Safety Analysis, Traffic Engineering/Design, Traffic Operations (maintenance and operations), Traffic Development Support (studies and research), Motor Carrier, and the Maryland Highway Safety Office. In addition he is responsible for the Highway Sign and Signal Shops and serves as one of 8 members comprising the Board that guides and directs the State's ITS program - CHART.



Mr. Hicks has served as the State Traffic Engineer for the Maryland State Highway Administration since 1968. Under the old State Roads Commission, he served as Assistant Chief Engineer for Traffic Safety, and later Assistant Chief Engineer for Traffic Engineering. In the early 1980s, as some states were cutting back on traffic engineering activities, the Maryland SHA began a significant effort to expand theirs, and Mr. Hicks position was elevated to Deputy Chief Engineer. In 1991, the Office of Traffic Engineering assumed control of the State's safety grant and Motor Carrier programs. The office then became known as the Office of Traffic & Safety. Maryland's traffic engineering program today is one of the most comprehensive in the country.

Prior to his Maryland assignments, Mr. Hicks was the State Traffic Engineer for the Oklahoma Department of Highways, becoming their first in this position. He is a graduate Civil Engineer with a BSCE from the University of Maryland and he completed the graduate school program of the Bureau of Highway Traffic at Yale University. Mr. Hicks taught traffic engineering for three years at the University of Oklahoma.

Mr. Hicks has served in leadership rolls with several professional organizations including ITE, AASHTO, NCUTCD, TRB, ATSSA, and the Safety Council of Maryland. He is currently a member of the AASHTO Standing Committee on Highway Traffic Safety, Vice-Chairman of the AASHTO Committee on Traffic Engineering, and a Member of NCUTCD where he served as Chairman, Construction & Maintenance Technical Committee. He is a member of the Washington DC ITE; served as a member of various TRB committees; and was a Co-Founder and first President of the Oklahoma Traffic Engineers Association. Mr. Hicks is the recipient of the National Safety Award from ATSSA; the 1991 Highway Safety Award from AASHTO; and the Community Transportation Award from the Washington DC Section of ITE. Mr. Hicks is the recipient of the 1999 Theodore M. Matson Award. He is a registered Professional Engineer in Maryland.

**PATRICK L. IRWIN**

Patrick Irwin was born and raised in San Antonio , Texas. He received a Bachelor of Science degree in Civil Engineering from Texas A&M University.

He began his career with the Texas Department of Transportation in 1974 with an assignment to the San Antonio District Traffic Section in freeway operations. His operations study of I-410 in San Antonio justified the first implementation in the state of turnarounds as well as x-configuration of ramps. An assignment in Atascosa County followed which involved the rural design of I-37. Next came an appointment to the San Antonio Special Design Group where he was the design team leader for several projects including the Fratt Interchange Project which in 1979 and at \$67 million was the largest Department contract. A six and a half year assignment as Supervising Resident Engineer for Frio and LaSalle Counties followed. In 1986, Irwin returned to the San Antonio District as District Traffic Engineer, responsible for traffic

operations for some 11,800 lane-miles of highways in sixteen South Texas counties. In 1992, he was appointed Director of Transportation Operations for the District. Mr. Irwin is currently responsible for the on going development of the San Antonio Advanced Traffic Management System (TransGuide) which is envisioned to be the most advanced system in the nation. TransGuide was the 1995 recipient of the ITS America Board Chair Award and was selected as a United States DOT Model Deployment Initiative Site.

Mr. Irwin has addressed and participated in numerous national, state and local Transportation groups. He was a primary developer and instructor of the Advanced Traffic Engineering course of TxDOT's Professional Development training program. He also has published papers in the fields of both transportation operations and transportation management.

He is a past Director of ITS Texas. In addition, he has been a guest lecturer at universities, serves as a resource for the USDOT's Peer-To-Peer Program and has provided consultation to 16 foreign countries in transportation management. Mr. Irwin also supports the Texas Transportation Federal Credit Union as a Director, Rotary Club past resident and a Superintendent of the Walter Gerlach Junior Livestock show & sale.

He was honored by TxDOT in 1995 with the prestigious High Flyer Award. This award was given for innovative risks in supporting TxDOT's mission of providing safe, effective and efficient movement of people and goods.

WAYNE K. KITTELSON

Wayne Kittelson is a Principal in the transportation consulting firm Kittelson & Associates, Inc. Throughout his career, Mr. Kittelson has been involved in a wide variety of projects related to transportation planning, traffic engineering, highway design, public involvement, and transportation research. He has also taught transportation related courses, and has developed and applied computer programs to facilitate various analytic procedures.

For over twenty-five years, Mr. Kittelson has been directly involved in a wide variety of applied research activities. Whether as a project participant, Project Manager, Panel Member, or Principal Investigator, he has assisted in the development and application of state-of-the-art techniques for accurate and realistic analyses of traffic operational and safety analyses on all types of facilities. Examples of recent research-

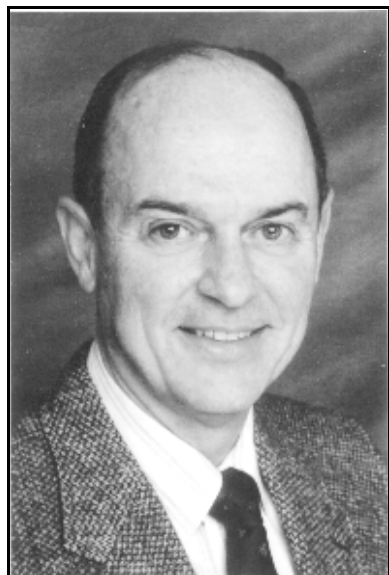
related activities in which Mr. Kittelson has had significant professional involvement include: NCHRP 3-46 (development of an unsignalized intersection analysis method); NCHRP 3-49 (Evaluation of the Operational and Safety Effects of Mid-Block Left-Turn Treatments); NCHRP 3-54 (Uniform Display for Protected-Permitted Left-Turn Phasing); NCHRP 3-55(2) (Development of Planning Applications for Estimating Speed and Level-of-Service); NCHRP 3-55(3) (development of a two-lane roadway analysis method); NCHRP 3-55(6) (Development and Delivery of a Year 2000 Highway Capacity Manual); TCRP A-15 (development of a Transit Capacity Manual); and an FHWA-sponsored project to develop a Roundabout Design Guide.

Mr. Kittelson also regularly serves as an instructor in numerous highway capacity analysis and intersection design courses given throughout the United States. He has been associated with the Transportation Research Board's Committee on Highway Capacity and Quality of Service since 1978, when he was a major contributor to an FHWA-sponsored research project entitled *Quality of Flow on Urban Arterials*. He has continued to stay involved in Committee activities since then, serving as both its Secretary and as Chairman of the Subcommittee on Interpretations and User Liaison. He participated directly in the development of the 1985 *Highway Capacity Manual*, the 1994 update, and the 1997 update.

In the area of design, Mr. Kittelson has previously served as an instructor for an FHWA-sponsored course entitled, "Design of Urban Streets." This course was given throughout the United States and in Puerto Rico, and continues to serve as a basic reference on urban street design standards and guidelines. Mr. Kittelson has presented short-courses on urban intersection design and operations issues.

Mr. Kittelson received his Bachelor of Science degree in Civil Engineering from Northwestern University and his Master of Science degree in Civil Engineering with specialization in Traffic and Transportation from the University of California at Berkeley. He has been a member of several professional organizations and served as the President of the Oregon Section of ITE. He is a registered professional engineer in Oregon and Florida.





H. DOUGLAS ROBERTSON

As a Vice President and Regional Operations Manager for SAIC's Transportation Consulting Group, Dr. Robertson directs the operations of four divisions located in six area offices currently serving clients in Virginia, Maryland, Connecticut, Pennsylvania, the District of Columbia, Florida, Alabama, Georgia, Arizona, New Mexico, and California. He leads business development efforts and contributes to application projects in the areas of intelligent transportation systems, transportation planning, traffic engineering, and highway design. Having worked in the public and private sectors and academia, he has a broad perspective of past, present, and future transportation needs and services.

Dr. Robertson also currently serves as SAIC's Senior Advisor for the Northeast Consultants (a joint venture with PB Farradyne Systems) who provide management support to the I-95 Corridor Coalition. The Coalition is made up of twenty-eight transportation agencies in twelve eastern states. He is also the Program Manager for the Development of Rural Intelligent Transportation Systems (ITS) Project, a \$10 million effort to provide technical support to U.S. DOT's rural ITS program.

While Director of Plans and Programs at ITS America, he co-chaired a joint effort with U.S. DOT to develop the National ITS Program Plan. In other previous positions, Dr. Robertson was a professor of civil engineering at the University of North Carolina at Charlotte and prior to that served in both the National Highway Traffic Safety Administration and the Federal Highway Administration of the U.S. Department of Transportation.

He is a Fellow of the Institute of Transportation Engineers and a former Group 3 Council Chair of the Transportation Research Board. He was the senior editor and a principal author of the *Manual of Transportation Engineering Studies* for the Institute of Transportation Engineers and has published over 60 journal articles and reports.

Brigadier General Robertson serves in the U.S. Army Reserves and is the Commanding General for the 108th Division (Institutional Training), a unit of over 3,400 soldiers with subordinate units located in the two Carolinas, Georgia, Florida, and Puerto Rico. He is a graduate of the U.S. Army War College and the recipient of numerous decorations and awards.

He received his Bachelor's degree in Civil Engineering from Clemson University, his Master's in Transportation Engineering from the University of South Carolina and his Doctorate in Civil Engineering from the University of Maryland. He is a registered professional engineer.

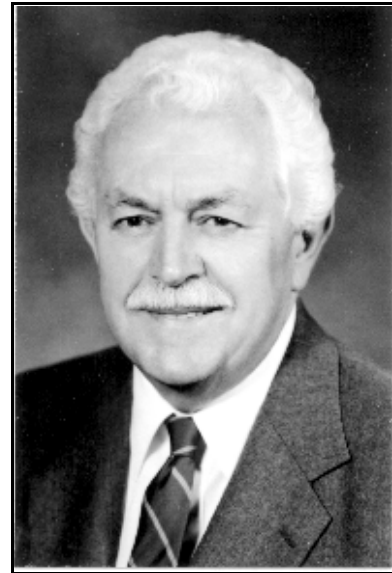
WILLIAM M. SPREITZER

Mr. Spreitzer received his B.Ae.E. in Aeronautical Engineering, from the University of Detroit in 1952 and P.Ae.E., Professional Aeronautical Engineering degree (Honorary) from the University of Detroit, 1957. He is a recognized world leader in Intelligent Transportation Systems (including AHS) and transportation research.

Mr. Spreitzer brings forty-six years of relevant experience to Intelligent Transportation Studies including advanced automotive gas turbine engine development; full-scale and on-the-road concept vehicle development in applications of gas turbines, advanced transmissions and automatic vehicle controls to automobiles (Firebird I, Firebird II and Firebird III), buses (TurboCruiser I and TurboCruiser II), heavy trucks (TurboTitan I and TurboTitan II) and a variety of wheeled and tracked military vehicles; direction of research development programs in advanced transportation systems (U.S. Department of Housing and Urban development Study of New Systems for Urban Transportation)

and interdisciplinary studies of transportation systems of the future--public and private/personal and transit and commercial (freight). Mr. Spreitzer retired from General Motors in January 1998 as Technical Director, General Motors ITS Program where he was responsible for planning and coordination of General Motors ITS Programs, corporate-wide and world-wide.

Mr. Spreitzer is active in national and international ITS efforts. He is past Chair of the ITS America Coordinating Council (1994-97); past Chair of the ITS America Futures Group; Chair of the Society of Automotive Engineers Technical Standards Board ITS Division and a member of the SAE ITS Program Office and past Chair of the United States Delegation to the International Standards Organization (ISO) Technical Committee 204, Transport Information and Control Systems (TICS).





CAROL A. ZIMMERMAN

Dr. Zimmerman has 20 years experience in marketing, education and consulting. Her areas of expertise have included new product analysis and definition for consumer and business markets, market management of intelligent transportation systems, social analysis of natural resource utilization, and quantitative research to support regional economic development. She has been a consultant to federal and local agencies, has served in a number of marketing roles for a global telecommunications firm, and has taught graduate and undergraduate students at U.S. colleges.

Dr. Zimmerman is Vice President and Director of ITS in Battelle Memorial Institute's Transportation Sector and is Relationship Manager for the ITS Joint Program Office at USDOT. She currently serves as project manager for Partners In Motion, a public/private partnership for delivering traveler information in the Washington, D. C. region. Battelle is the systems integrator for this \$12.2 million project, which began operation on July 1, 1997. Dr. Zimmerman is responsible for all aspects of the project, which consists of twenty-six public agencies and thirteen private sector firms working together to implement a system for providing real-time information to travelers over a wide variety of delivery platforms.

Dr. Zimmerman also serves as program manager for Battelle's work on ITS Program Evaluation Support (IPAS), a broad-ranging effort by USDOT's ITS Joint Program Office to assess the benefits and impacts of ITS projects around the country, such as the Metropolitan Model Deployment Initiatives, CVISN, Federal Operational Tests, and other projects.

Previously, Dr. Zimmerman managed end-user testing and public relations for the Atlanta Traveler Information Showcase during the summer of 1996. She had direct responsibility for planning, implementation, and assessment of the users of the information delivery technologies being showcased, in addition to supervising the entire public relations program for the Showcase. Dr. Zimmerman designed and managed a multi-million dollar market research effort for the USDOT ITS Joint Program Office to gauge acceptance of intelligent transportation technologies among consumer, commercial, and government markets and has been a consultant on ITS telecommunications issues at USDOT.

Prior to Battelle, Dr. Zimmerman initiated AT&T's program in intelligent transportation systems and later managed the cross-business unit team marketing communications infrastructure products and services to state and local transportation agencies. Dr. Zimmerman served as Assistant Professor at Rutgers University, where she taught courses and conducted research in environmental management. At Southern Connecticut State College and Central Connecticut State College, Dr. Zimmerman served as Lecturer in Geography, teaching courses in physical and cultural geography, urban geography, and natural resource conservation. At Harconn Associates, a consulting firm in Connecticut, Dr. Zimmerman led the firm's activities in computer modeling and analysis of regional industry and labor markets.

Dr. Zimmerman received her Ph.D. from Yale University, where she focused on the sociology of resource utilization within the School of Forestry & Environmental Studies. She is an active member of ITS America, where she has served on the Coordinating Council and many committees. She serves on the Advisory Board of the Center for Advanced Transportation Technology at the University of Maryland.

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**AN EVALUATION OF THE POTENTIAL OF PUBLIC/PRIVATE
PARTNERSHIPS FOR THE MANAGEMENT OF ARCHIVED ITS DATA**

by

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EXECUTIVE SUMMARY

Transportation professionals must have reliable data for their planning and operations purposes. Every day, vast amounts of valuable data are generated by ITS throughout the country, but much of these data are not effectively archived for future use. It is expensive to archive ITS data into a manageable form, and most public sector agencies that produce these data cannot afford to archive the data efficiently. Public/private partnerships have been developed for the dissemination of real-time traveler information, and the same types of partnerships can be developed for the management of archived ITS data.

In this research the author identified transportation systems that archive ITS data; identified potential users of archived ITS data; determined public and private sector benefits from investing in the archival of ITS data; evaluated existing public/private partnerships developed to access real-time traffic information; developed potential strategies of public private partnerships for managing archived ITS data; and performed a case study by implementing the results in San Antonio, Texas.

A review of literature was performed that focused on the following: primary ITS data-generating technologies, agencies that archive ITS data, public/private partnership business models, and successful public private partnerships. To supplement the literature review, the author interviewed five public sector agencies that archive or manage ITS data and three private sector individuals that have an interest in archived ITS data.

Using the results of the literature review and the interviews, guidelines were developed to help the public and private sectors form partnerships in the management of archived ITS data. These guidelines included the following:

- Create framework for the archived ITS data system.
- Select private sector partners.
- Negotiate the contract.
- Amend differences among partners.
- Create the archived ITS data management system.

These guidelines were applied to a case study in San Antonio, Texas, where a hypothetical data management system was developed.

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INTRODUCTION

Large quantities of valuable traffic data are generated by Intelligent Transportation Systems (ITS). These data are collected by Traffic Management Centers (TMCs) and used primarily for real-time applications, including transit, freeway, and incident management, and traffic signal control. If these data are stored for future use in a manageable and useful format, the ITS-generated data could also be utilized in other applications, such as transportation planning and operations purposes. The use of these data for other purposes results in a value-added situation. In this report, the term “ITS data” will refer to data generated using various ITS technologies.

Loop detectors are an important method of collecting traffic volume, lane occupancy, and average speed data. Loop detector stations are permanent, thereby allowing greater quantities of information to be collected than with manual collection methods. Local controller units (LCUs) store and aggregate the loop detector information in the field. Computers at the traffic management center (TMC) retrieve the information from the LCUs. For example, the TransGuide loop detector system in San Antonio, Texas, collects continuous volume, occupancy, and speed data, which is aggregated into twenty-second intervals, totaling approximately 150 megabytes of data each day. It is important to save these data in a way that they can be aggregated into any desired time period and accessed with an easy-to-use computer interface (1). If information from loop detectors is properly saved, it can be easily used by transportation professionals who need accurate information about traffic performance characteristics (1). The characteristics include vehicle volumes, travel times, and speed data.

In recent years, the private sector has become financially involved in the transportation system through public-private partnerships. The public sector has an infrastructure of roadways and the private sector invests money with the expectations of making profit from their investments. For example, the private sector invests in toll roads and receives a percentage of the revenues. Other private sector business ventures include the installation and sale of excess telecommunications lines and the creation and sale of traveler information services.

Problem Statement

Transportation professionals must have reliable data for their planning and operations purposes. Vast amounts of valuable data are generated by ITS equipment throughout the country, but much of these data are not effectively archived for future use. It is expensive to archive ITS data into a manageable form, and most public sector agencies that collect these data cannot afford to archive the data efficiently. Public-private partnerships have been successful in increasing the number of travelers that access real-time traffic information. Some similar business strategies must be developed to involve the private sector in the archiving of ITS data. To justify private sector participation, benefits from investing in the archiving of ITS data must be determined.

Research Objectives

The primary objective of this study was to investigate the potential for private sector investment in the archiving of ITS-generated data. The objectives of this study were as follows:

- Identify transportation systems that archive ITS data;
- Identify potential users of archived ITS data;
- Determine private sector benefits from investing in the archival of ITS data;
- Evaluate existing public-private relationships for accessing real-time traffic information;
- Develop potential strategies of public-private partnerships for managing archived ITS data; and
- Perform a case study by implementing the results in San Antonio, Texas.

STUDY DESIGN

In examining the potential of developing public/private partnerships for managing archived ITS data, the author's research consisted of three primary tasks: a literature review, data collection, and data analysis and application. This section of the report discusses these tasks.

Literature Review

A review of current literature was conducted, focusing on the technologies used to collect ITS data, agencies that archive ITS data, uses and benefits of ITS data, public/private partnership strategies, and successful public/private partnerships.

Data Collection

To supplement the information from the literature review, a survey of six state agencies and three private individuals that are involved with archived ITS data was conducted. The survey was performed through telephone interviews and written correspondence. Separate sets of questions were developed for the public and private sectors. The questions asked were the following:

Public Sector

1. Does your organization generate information through the use of loop detectors?
2. Does your organization generate information through other types of ITS?
3. Is the ITS information saved by your organization?
4. Who uses your organization's archived ITS data, and what type do they use?
5. For what applications do they use the data?
6. How do the users of your organization's data acquire it?
7. What method is there for accessing the information that your organization saves?
8. Do you see the potential for the development of public/private partnerships in managing archived ITS data?
9. What are the benefits and problems associated with public/private partnerships for managing archived ITS data?

Private Sector

1. Do you perceive a market for archived data generated by ITS?
2. What types of data are needed and in what form are they needed?
3. How is the data acquired?
4. For what purposes do you need the archived data?
5. Is your company currently involved in public/private partnerships?
6. Do you see the potential for the development of public/private partnerships for managing archived ITS data?
7. What are the benefits and problems associated with public/private partnerships for managing archived ITS data?

Data Analysis and Application

The information gathered in the literature review and interviews were used to develop guidelines for public/private partnerships for managing archived ITS data. The guidelines are comprised of existing strategies used in partnerships that disseminate real-time traveler information and new guidelines that apply to archived ITS data. Finally, a case study was performed that used the guidelines in the development of a hypothetical data management system in San Antonio, Texas.

ARCHIVED ITS DATA

Intelligent transportation systems include many different areas of transportation, one of which is the Advanced Traffic Management Systems (ATMS). The purpose of ATMS is to monitor the current traffic situation and to identify any unusual occurrences in the traffic flow, such as incidents (2). These systems can also be adapted to provide information to Advanced Traveler Information Systems (ATIS). ITS data are primarily used in real-time for the purposes of monitoring traffic conditions. The increasing deployment of ITS across the nation generates data that can be used for purposes other than real-time traffic monitoring.

ITS Data Technologies

The two primary technologies that produce data that are archived are loop detectors and Automatic Vehicle Identification (AVI).

Loop Detectors

Loop detectors consist of a wire buried in or placed just below the surface of the pavement. An electric current is sent through the loop by attaching it to a power source, which creates an electromagnetic field. When a vehicle passes over the loop, the energy of the system is reduced causing the inductance to decrease. The decreased inductance causes the detector's electronic circuits to generate a pulse, which is sent to traffic counters or signal controllers to monitor traffic (3). Loop detectors are positioned in either single-loop or double-loop configurations. Single loop detectors acquire vehicle volume and lane occupancy information. Double-loop detectors can also be used to acquire volume and occupancy information using the first loop, while spot speeds are determined using both loops by calculating the difference in arrival times between consecutive loops (1). Loop detector information is sent to local controller units (LCUs), which aggregate the information in the field. Computers at the traffic management center (TMC) retrieve the information from the LCUs.

An example of twenty-second loop detector data from the TransGuide loop detectors is shown in Figure 1. These data were obtained from the website, "ftp://www.transguide.dot.state.tx.us/lanedata/." Each line is a twenty-second report for a specific detector, which includes the date, time, location, speed, volume, and lane occupancy for that detector.

DATE	TIME	LOCATION	SPEED	VOLUME	OCCUPANCY
06/18/99	18:24:28	L1-0090E-571.712	Speed=77	Vol=005	Occ=005
06/18/99	18:24:28	L1-0090W-571.712	Speed=78	Vol=002	Occ=002
06/18/99	18:24:28	L2-0090E-571.712	Speed=60	Vol=006	Occ=006
06/18/99	18:24:28	L2-0090W-571.712	Speed=73	Vol=004	Occ=014
06/18/99	18:24:28	L3-0090E-571.712	Speed=64	Vol=007	Occ=010
06/18/99	18:24:28	L3-0090W-571.712	Speed=67	Vol=002	Occ=002
06/18/99	18:24:28	L4-0090E-571.712	Speed=63	Vol=011	Occ=009
06/18/99	18:24:28	L4-0090W-571.712	Speed=67	Vol=003	Occ=003
06/18/99	18:24:28	L5-0090E-571.712	Speed=65	Vol=009	Occ=009
06/18/99	18:24:28	L5-0090W-571.712	Speed=64	Vol=004	Occ=004
06/18/99	18:24:28	L1-0281N-146.354	Speed=65	Vol=003	Occ=003
06/18/99	18:24:28	L2-0281N-146.354	Speed=63	Vol=007	Occ=007
06/18/99	18:24:28	L3-0281N-146.354	Speed=56	Vol=006	Occ=006
06/18/99	18:24:28	L1-0281S-146.354	Speed=45	Vol=012	Occ=013

Figure 1. Sample of Loop Detector Data

Automatic Vehicle Identification

AVI allows traffic center operators to track probe vehicles uniquely through wireless communication (5). An AVI system consists of four primary components:

- Probe vehicles carrying electronic transponders;
- Roadside antennas that detect transponders;
- Roadside readers that bundle data; and
- A central computer facility that collects and interprets data and calculates travel time.

In an AVI system, roadside antennas broadcast radio frequency energy over the freeway. The area that is covered by this is called the read zone. When a vehicle is in the read zone, the transponder deflects a small part of the energy back to the antenna. These radio waves recognize the tag’s unique ID and other data. The captured information is sent to the roadside reader via coaxial cable, and the vehicle is assigned a unique time and date stamp. These data are typically sent to the central computer facility via telephone line where they are processed and stored (4,5).

AVI is most useful for direct calculation of travel times and can be as accurate as 99 percent for this use. Since there are no personnel required for field data collection, travel times can also be calculated for long periods of time. The major disadvantage of AVI is that the data collection is limited to the probe density, so AVI cannot be used for volume counts. Another disadvantage of AVI is that the capital, installation, and maintenance costs are very high. Motorists are also concerned about their personal privacy, since each AVI transponder has a unique identification number (4).

An example of AVI data from the TranStar AVI system is shown in Figure 2. Each line indicates a vehicle with a transponder reaching an AVI station. Each record includes the date, the station, the cumulative time in seconds, the vehicle identification number, and the travel time in seconds between that station and the next station.

Day	Station	Time	ID	TT
1	1	7	44082	468
1	1	8	21321	403
1	1	46	134902	397
1	1	64	6537	406
1	1	259	151320	219
1	1	291	95711	377
1	1	438	23445	545
1	1	442	23446	542
1	1	464	20760	217
1	1	494	122907	467
1	1	506	73088	388
1	1	516	1812	440
1	1	553	35864	522
1	1	582	132015	471
1	1	604	124372	513
1	1	615	147352	451
1	1	646	155844	442

Figure 2. Sample of AVI Data

ITS Data Management Systems

Due to the large quantities of data generated by ITS equipment, data management systems must be designed, so that they can store these data and allow users to quickly access the data that they desire. This section of the report will examine some important issues that need to be considered when developing a data management system.

Data Storage

Enormous quantities of data are generated by ITS. For example, the TransGuide loop detectors produce over 50 gigabytes (GB) of data per year. There are many options for storing these data, which include magnetic disk, compact disk (CD), digital video disk (DVD), optical disk, and hard drive (6,7).

Data Access

Most databases require users to know a programming language, but it is preferable to allow users to access data on their desktop computer without knowing any special languages. A simple, easy-to-use interface would allow a wide variety of users to access the data. A web browser interface would be ideal because of the familiarity of most users with the internet (7).

Data to Information

It is ideal to convert the large quantities of ITS data into easy to understand information. Transportation planners need to analyze trends in freeway corridors or systems for long periods of time, which could mean converting gigabytes of data into one page of useful information. This process is known as “data mining”(7).

STATE-OF-THE-ART LITERATURE REVIEW

Agencies That Archive ITS Data

There are many agencies that archive ITS data. This section contains information about specific TMC's and what types and quantities of data they are archiving.

INFORM

INFORM (INformation FOR Motorists) monitors 35 miles of the central corridor of the Long Island Expressway. The Center polls the loop detectors 60 times per second. The data are aggregated into quarter-second, 1- minute, and 15-minute intervals at the Center. The single loop detectors are located in each lane at half-mile intervals. The 15-minute data are saved for three months to tape; then the tapes are overwritten (6).

Houston TranStar

The Houston TranStar Traffic Management Center provides traffic management for 160 miles of the Houston freeway system. The loop detectors cover about 30 miles of the freeway system and are spaced at half-mile intervals. Loop data are sent to the center approximately every twenty seconds. Houston also has an extensive AVI that has over 300,000 tags in circulation. The AVI system reads are sent to the center in real-time as they occur. The AVI data are aggregated into 15-minute intervals and saved for future use (6,7,9, 10).

Illinois Traffic Systems Center

The Traffic Systems Center monitors 130 miles of freeway with approximately 2,250 single loop detectors. The detectors are located every three miles in all freeway lanes and collect volumes and lane occupancies. Approximately every half-mile a loop detector is located in the center lane, which is used to estimate travel time. The data are collected every 20 seconds and are aggregated to the five-minute level. Only the travel time and lane occupancy during peak hours are saved at this level. Hourly volumes across all lanes are also saved. The data are saved on magnetic tape (6,7).

Los Angeles (Caltrans District 7) Traffic Management Center

The Los Angeles (Caltrans District 7) TMC monitors 748 directional miles of roadway. The system consists of over 1,000 loop stations at half-mile intervals. The stations consist of single loops that are polled every 30 seconds. The 30 second data have been permanently archived to magnetic tape since the center opened. The TMC is in the process of developing a new system for archiving and accessing ITS. The new system will make 13 months of ITS data available online through a relational database. Beyond the 13 month period, the data will be saved to magnetic tape (6,7).

Michigan Intelligent Transportation Systems Center

The Michigan Intelligent Transportation Systems Center consists of two systems that combine to cover over 180 miles of freeway in the Detroit area. The old system consists of single loop detectors that cover 32 miles and are spaced at approximately one-third-mile intervals. The new system consists of double loop detectors that cover 150 miles spaced at two-mile intervals. The data are aggregated in the field at 20-second intervals and sent to the center. The data are aggregated at the center into one-minute volume, occupancy, and speed and are saved. The center keeps data on-line for one week; then the data are transferred and saved on tape (6,7).

Minneapolis, Minnesota Traffic Management Center

The Minnesota Traffic Management Center monitors 175 miles of freeways in the twin cities metropolitan area. The system consists of approximately 3,000 loop detectors that are in place at half-mile intervals. The loops collect average volumes per lane across lanes at each location, lane occupancy, and vehicle length. The average speeds are estimated from the loop detector data. Loops are polled by the Center every 30 seconds as an average across lanes. Every five minutes the data are aggregated and saved on hard disk in a compressed format. Daily information is compressed and stored on a CD. (6,7).

North Seattle Advanced Traffic Management System

The North Seattle Advanced Traffic Management System monitors approximately 100 miles of freeway in the Seattle Area. Loop detectors that collect volume, speed, and lane occupancy information are placed at half-mile intervals. These stations send data to the center every 20 seconds. The loop detector data are stored at the five-minute aggregation level. Six months of these data are saved onto a CD and are available to anyone who requests it (6).

Phoenix Traffic Operations Center

The Phoenix Traffic Operations Center monitors approximately 41.5 miles of freeway with single loop detectors that are spaced at approximately one-third mile intervals. The loops collect volume, vehicle length, speed, and lane occupancy. The TOC has saved all 20-second data since the center opened in 1995. Five-minute summaries of the data are also created and saved (6,7).

San Antonio Transguide

The city of San Antonio was selected as one of four cities for national deployment of the Intelligent Transportation Infrastructure (IFI). The TransGuide system covers approximately 55 miles with loop detectors placed at approximately half-mile intervals. The loop detectors collect volume, lane occupancy, and speed data. The loop detector data are sent to the TransGuide computers approximately every 20 seconds. The loop detector data are saved for future use and also made available on the internet. The AVI system in San Antonio covers 97.5 miles. The AVI system collects travel time and average speed data. The ID numbers are scrambled so that the individual drivers cannot be identified (6-8).

Toronto’s COMPASS

COMPASS is a traffic management system that monitors parts of highway 401 in Toronto, Canada. There are approximately 400 loop detector stations with 2,800 loops that cover 22 miles and are spaced at intervals of half-mile or less. The stations are polled every twenty seconds and the data are aggregated into five-minute, 15-minute, one hour, daily, and monthly time periods. Traditionally, the data were archived on 8 mm tapes, but since 1997 the system has been saving the data on CD (6,7).

TRANSCOM

TRANSCOM (the Transportation Operations Coordinating Committee) coordinates traffic management in New York, New Jersey, and Connecticut. TRANSCOM has a project called TRANSMIT that uses vehicles with AVI transponders (6). The purpose of these AVI stations is the collection of speed and travel time data to be used for incident detection. The organization saves information into 15-minute time periods.

Summary

The loop detector systems that were discussed in this section are summarized in Table 1. The amount of centerline miles that the system covers, the approximate spacing between consecutive detector stations, the level of aggregation, and the media to which the data are aggregated are summarized in the table. The same information is summarized for the AVI systems in Table 2.

Table 1. Summary of Traffic Management Center Loop Detector Data Archiving Practices

TMC	Coverage	Spacing	Archival/Availability
San Antonio TransGuide	55 mi	0.5 mi	20-second data available on internet
Houston TranStar	30 mi	0.5 mi	None
Minneapolis TMC	175 mi	0.5 mi	5-min data available on CD
Phoenix TOC	41.5 mi	0.33 mi	20-sec data saved. 5-min data easily accessed
Michigan ITS	32 mi (1) 150 mi (2)	0.33 mi (1) 2 mi (2)	1-min data saved to tape. One week available online.
Illinois TSC	130 mi	3 mi	1-hr data saved to tape
Los Angeles TMC	748 mi	0.5 mi	30-sec data saved to tape
North Seattle ATMS	100 mi	0.5 mi	5-min data saved to CD
Toronto Compass	22 mi	0.5 mi	5-min data saved to CD since 1997
INFORM	35 mi	0.5 mi	15-min data saved for 3 months

Table 2. Summary of Traffic Management Center AVI Data Archiving Practices

TMC	Coverage	Spacing	Archival/Availability
San Antonio Transguide	97.5 mi	1.0 mi - 2.0 mi	24-hour data saved
Houston TranStar	227 mi	0.9 mi - 6.7 mi	15-min data saved
TRANSCOM		1.5 mi	15-min data saved

PUBLIC/PRIVATE PARTNERSHIPS

A gap exists between the ITS technology that is available and the funds that the public sector has to spend on ITS. The public sector has become involved in public/private partnerships to remedy this problem. A public/private partnership is a combining of resources among entities within the public and private sectors that achieves the goals of the individual partners by providing a service to others. In the partnership it is important that both parties benefit: public agencies better utilize their resources, private companies increase the market for their goods and services, and users get a more complete service than either group could provide alone. Most existing public/private transportation partnerships involve Advanced Traveler Information Systems (ATIS), which will be discussed in this section of the report (11-13).

Advanced Traveler Information Systems (ATIS)

ATIS allows motorists to make more informed travel decisions, such as route planning and selection of travel mode, by providing travelers information prior to a trip or during a trip. ATIS also provides travelers real-time information such as traffic congestion, roadway incidents, and other travel conditions. The information provided can be expanded to an intermodal level, providing information about transit and airline departures and arrivals (14).

There are three major functions of traveler information services: data gathering, data fusion and processing, and data dissemination. The data gathering phase describes the receiving of information. This stage includes data collection and transforming the collected data into relevant information. The data fusion and processing phase includes consolidating data from many sources in the same area. Any additional value added to the data is also performed in this step. Data dissemination is the delivery of the information to consumers (11).

Public Sector and Private Sector Differences

In forming partnerships, the public and private sectors view operations differently, so for a partnership to be successful, it is important to try to bridge the gap between the two views. According to Hallenbeck et al., the public and private sectors view ATIS very differently.

Goals

In forming public/private partnerships, the primary goal of the public sector is to improve the quality of transportation for the citizens. This includes improved safety, decreased congestion, improved economic situation of the region, decreased fuel consumption, and improved air quality. The primary goal of the private sector is to make a profit (15).

Costs

The public sector is concerned with political costs, costs of using scarce resources, and the environmental and social costs. The private sector is concerned with the capital and operating cost of the project (15).

Performance Indicators

The level of service indicators that the public sector is concerned with are measures such as level of service, ridership, air quality, and public support. The measures that the private sector is concerned with are sales, market share, and net profit (15).

Public/Private Partnership Business Models

There are many forms that public/private partnerships can take. This section of the report will examine some of the public/private partnership “business models.”

Public Sector Emphasis

In the public sector emphasis model, the local or state transportation agency has full authority and responsibility to operate the traveler information system. The data are primarily collected, processed, and disseminated by the public sector. In this model, large quantities of information are given to the public by the public sector, which reduces the business opportunities of the private sector. The lack of financial interest by the private sector makes the public sector provide most of the funding, but it also allows the public agency to have a high level of control over the operation of the system. If more than one agency is involved, it is referred to as a public-public partnership (13-15).

Contracting

This model is a variation of the model described above. In contracting, the public agency hires a private firm to perform a specific portion of the project. This allows the private sector to utilize personnel that are more likely to be experts in the processing and dissemination of data and reduce the manpower needs of the public sector (14,15).

Franchising

Franchising relies on the public sector only for data collection, which is a function that is already performed by the Advanced Traffic Management Systems. The data are collected by the public sector, and the government awards an exclusive distribution franchise to a single information provider after a competitive bidding process takes place. In return, the provider is allowed to sell the data to other Independent Service Providers (ISPs) and consumers as a way to generate revenue. The advantage of this model is that it pushes the majority of the operation and maintenance expenses to the private sector. This model also allows the private sector to tailor the product to the needs of the end-users. Franchising raises the question of social equity. Since the product is purchased by consumers, people who are poor are less likely to have access to travel information. Another disadvantage is that if the public sector uses software that remains owned by the private sector, it is difficult to change contractors at a later date (13-15).

Competitive Licensing

Competitive licensing is an agreement in which the public sector allows two or more franchises in the same area to obtain traffic data collected by the public agency and market it to consumers. This situation is not as profitable for the private sector, but the competition creates better, lower cost access to traveler information (14,15).

Asset Management

In asset management, the public sector produces the data and disseminates the data through the services of an outside broker. The broker sells the data to wholesalers and retailers in exchange for a commission. The public sector maintains ownership of the data, but new markets are opened up through the expertise of the broker (14).

Joint Ownership

In joint ownership, the public agency agrees to jointly operate a traveler information system with one or more private sector firms. Typically, both partners are responsible for the collection of data, the private sector merges the data, and the both groups disseminate the information (14).

Cost Sharing

Cost sharing involves the public and private sectors sharing the costs in the design, construction, operation, and maintenance of the traveler information system. The revenue generated is split between the two groups. This strategy is used when both groups benefit from the system (14).

Private Sector Emphasis

In the private sector emphasis model, the private company performs all the data collection, processing, and dissemination functions. This information is collected by state-of-the-art technologies and is processed into useful traffic reports. These reports are provided to subscribing TV and radio stations in a format that they desire. In this model, the private sector owns and operates the entire system. This gives the private company more incentive to produce a product that has a great potential to generate revenue. One drawback of this model is that it may not generate a sufficient amount of revenue for future expansion of the transportation data collection system (14).

Summary

In this section, various types of public/private partnerships were described. Table 3 summarized each sector's role in each type of partnership regarding the data gathering, data fusion, and data dissemination aspects of ATIS.

Public/Private Partnership Examples

This section of the paper will examine examples of existing successful public/private partnerships.

Partners In Motion

Partners in Motion is a public/private partnership that consists of 26 public and 13 private sector entities in the Washington D.C. area. It was officially announced in 1997 and is an information system that was developed to help travelers make better decisions and help agencies better coordinate their efforts in managing congestion. The partnership has a \$12.2 million budget for the first three years, which is divided into \$8.3 million in public funds and \$3.9 million in private funds. The purpose of the public funding is to assist in the formation of a market for the traveler information. After three years, the traveler information service is designed to become self-supportive and will operate totally privatized (16).

Table 3. Public and Private Sector Roles and Various Partnership Models

Business Model	Data Gathering	Data Fusion	Data Dissemination
Public Sector Emphasis	Public	Public	Public/Private
Contracting	Public	Private	Public
Franchising	Public	Private	Private
Competitive Licensing	Public	Private	Private
Asset Management	Public	Public	Private
Joint Ownership	Public/Private	Private	Public/Private
Cost Sharing	Public/Private	Public/Private	Public/Private
Private Sector Emphasis	Private	Private	Private

The public and private sectors have different risks and rewards from this project. The public sector’s risk is that they may start a service that travelers rely on with the possibility of the loss of funding for the project. The public sector is rewarded and by having better informed travelers and a new source of ITS funds. The private sector risk is that they may not make a profit on their investment. The private sector is rewarded by a profitable business venture (16).

There were some technical considerations when the partnership was in its developmental stages. Two of the public agencies involved were in the process of developing new traffic management systems, so Partners in Motion would have to wait for the completion of those projects before data in those areas would be available. The second consideration was that the management of data flows is typically labor intensive, so they wanted a design that would reduce the workload of the operations staff. The third consideration was that the system needed to conform to the ITS National Architecture as close as possible (16).

Smart Trek

As a part of the United States Department of Transportation Model Deployment Initiative (MDI), a group of twenty-five public agencies and private companies are working together to improve Seattle’s traffic management system. The purpose of this program is to better utilize the Seattle area ITS infrastructure. Existing data sources will be integrated with new data sources to establish an information network that is integrated, regional, and multi-modal. The initial project budget was \$17.8 million, with the United States Department of Transportation providing 77 percent, the Washington Department of Transportation providing 10.5 percent, and the private sector providing 12.5 percent (17).

The primary project goal is to improve transportation for the regional traveler by providing the following (17):

- reduce travel time by 15 percent;
- increase system efficiency;
- increase acceptance and awareness;
- increase safety by 10 percent;

- improve traveler information distribution by 25 percent;
- decrease emissions from energy consumption; and
- demonstrate the cost-effectiveness of an overall integrated ITI.

INTERVIEW RESULTS

Five public sector and three private sector representatives were interviewed about the uses of ITS data and the potential of forming public/private partnerships in the management of archived ITS data. The public sector was interviewed about the types of data that they collect or manage and the current practices involving the archival and management of the data. The private sector was interviewed regarding the potential uses of archived ITS data. Both sectors were asked their opinions about their archived data needs and the formation of public/private partnerships for managing the archived data.

Public Sector

All of the public sector representatives interviewed either represented an agency that collects ITS data or an agency that manages ITS data that another agency collects. Each interviewee’s name, the agency that they represent, and the agency that collects the data that they are reporting about are listed in Table 4. The results of the public sector interview questions are summarized in this section of the report.

Table 4. Public Sector Interviews

Name	Agency (Agency that collects data)
Steve Connell	Texas Department of Transportation (TransVISION)
Mark Hallenbeck	University of Washington (Washington DOT)
Pat Irwin	Texas Department of Transportation (TransGuide)
Brian Smith	Virginia Transportation Research Council (Virginia DOT)
Sally Wegman	Texas Department of Transportation (TranStar)

ITS Data Practices

Data Collection. The data that are presently collected are primarily collected through the use of inductive loop detectors, automatic vehicle identification, and closed caption television (CCTV). TransGuide also collected data through the use of acoustic detectors. The inductive loop detectors are used to collect traffic conditions data and incident data. Traffic conditions data consist of the following: lane occupancy, average speed, and traffic volume. Incident information includes location, lanes affected, duration, and queue length. The incidents are predicted by detecting variations from expected traffic conditions. Automatic vehicle identification is primarily used to collect travel time information. CCTV uses video cameras to monitor traffic and collect incident information. Acoustic detectors and loop detectors collect similar information (18-20).

Data Archival and Aggregation. There were no consistencies in the data archival and aggregation practices of the agencies that were represented by the interviewees. TransGuide archives all of the loop detector data that they generate and aggregates it into 20-second increments. The Washington Department of Transportation aggregates their loop detector data to 5-minute intervals and saves it on CD. TranStar saves

all of their AVI data, but none of their loop detector data. The Virginia DOT does not archive any data for long-term purposes, but they are experimenting with the possibility of archiving their loop detector and AVI data for future use. TransVISION is still under development, and they plan to retain large quantities of information generated by their existing and proposed detection technologies (18-22).

Data Management. There are two ways that public agencies are currently managing the data that they archive: hire an internal data manager or have a research organization manage the data for them. The TranStar representative cited that an internal data manager is difficult to retain at a public agency because they cannot afford to pay a database expert a competitive salary. Since researchers are the primary users of archived ITS data, they acquire this information from the traffic management centers in a raw form and archive the data based on their needs (18,21).

Data Access. The agencies that archive or plan to archive ITS data for the purposes of letting others access it use two primary methods: internet or CD. Two other ways that data are made available are electronic spreadsheets and paper. The Washington DOT archives 5-minute data and makes it available to anybody that wants it. TransGuide makes all of their 20-second data available on the internet to be downloaded (18,19).

Public/Private Partnerships

Benefits. There were mixed opinions from the public sector representatives regarding their opinions about public/private partnerships. Several benefits resulting from the formation of public/private partnerships were cited. In the management and access of the data, the private sector would have better resources to determine how to market the data and tailor it to the needs of the end user. Also, by having greater quantities of data reach the public, there would be increased support of future ITS activities (18).

Problems. There were also many problems resulting from the formation of public/private partnerships that were cited. For security reasons, the public sector is concerned about allowing information on the other side of the firewall. There are also questions about the accuracy of the ITS data, and in order for the private sector to market the data, some accuracy must be established. There is no evidence that adding value to ITS data and selling it is profitable, so until a market is established, the private sector will be hesitant. Because AVI tracks individual vehicles, it has the potential to violate the privacy of individual motorists. These privacy concerns may delay the acceptance of ITS data by the general public. A final concern about the formation of public/private partnerships is the varying needs of the end users. Some end users prefer to receive raw data and aggregate it to their needs, while other end users only want hourly or daily volumes. It may be too expensive to create a archived data system that will meet the needs of all potential end users (19-21).

Private Sector

The individuals from the private sector that were interviewed and the organizations that they represent are summarized in Table 5. The results of the interview questions are summarized in this section of the report.

Market for Archived ITS Data

Since the private sector is more familiar with the marketing of products, they were asked who they thought would be the potential users of ITS data. The following potential users were mentioned (23-25):

Table 5. Private Sector Interviews

Name	Organization
Uday Nagendran	U.S. Wireless
Raymond Starsman	ITS America
Robert Winick	Motion Maps

- Academic;
- Transportation agencies;
- Information service providers;
- Insurance companies;
- Wireless telephone providers; and
- Private consulting companies.

Uses of Archived ITS Data

The primary users of archived ITS data have been planners and researchers from the public sector. The applications of ITS data extend beyond the current users of the data. The most important of the other potential users are the private sector companies that see benefits because this could spark investment in the archival of ITS data. This section of the report examines public and private sector uses of archived ITS data.

Monitoring of System Performance. Transportation professionals from state departments of transportation must justify the benefits that resulted from prior funding to receive funding for future transportation projects. Loop detector data that is collected daily can be used to track trends in a transportation system. These daily comparisons will allow public sector transportation professionals to show system improvements from prior funding and the potential for more improvements from additional funding. (23).

Traffic Impact Assessments. It is important to be able to assess the effects that land development has had on traffic and parking patterns. Traditionally data that are used for these types of studies are collected for short periods of time and adjusted. With archived ITS data, the traffic conditions before and after land development for cases all over a region can be easily acquired (23,24).

Improved Travel Demand Models. Travel demand models are periodically updated to reflect people's behavior changes as their surrounding conditions change. The data input into these models typically come from traditional sources, such as interviews and responses to travel questions for the United States Census. If AVI data were used to supplement the origin-destination inputs, large quantities of ITS data could supplement the existing data (26).

Prediction of Future Traffic Conditions in the Short-Term. The purpose of ATIS is to inform travelers of real-time travel conditions. An added benefit of ATIS could be short-term predictions of future traffic conditions based on historical traffic information. With access to an archived ITS database, the Independent Service Providers (ISPs) could provide this information (20).

Improvement of Wireless Telephone Networks. A new ITS technology tracks users of wireless telephones. The wireless telephone companies can access the archived data to follow the travel patterns of their users. From this information, the wireless phone companies can expand their networks to reflect their users' travel patterns (25).

Incident Information. The automobile insurance industry acquires accident information. Since TMCs note incidents that happen within their boundaries, insurance companies would probably find value in acquiring this information from the TMCs (24).

Public/Private Partnerships

Benefits. All of the public sector representatives that were interviewed felt that the formation of public/private partnerships for the management of archived ITS data would be beneficial. Several benefits resulting from the formation of these partnerships were cited. It will be an expensive process to deploy a standard archived ITS data format across the nation, so the formation of partnerships would probably make this goal more attainable. Some ITS data resides in the private sector and some resides in the public sector, so by forming partnerships, these data could be combined. The private sector has better knowledge of what the market desires than the public sector, so the private sector feels that it can add beneficial qualitative value to the quantitative public sector data (23-25).

Problems. There are also some potential problems that could slow the formation of partnerships that the private sector representatives mentioned. It is believed that the public sector tends to delay projects more than the private sector, so by forming partnerships, the private sector would experience longer project delays. There appears to be a market for archived ITS data, but until somebody tries to sell it, nobody knows if it will be profitable. Therefore, there is a risk associated with the investment in the archived ITS data (23-25).

Example Application of Archived ITS Data

The results of the interviews were used to demonstrate how the public sector and private sector can form a partnership that benefits the public sector, private sector, and general public. This section uses TransGuide as an example, and demonstrates how those groups of people can benefit from the formation of a public/private partnership.

The TransGuide loop detector system collects over 150 megabytes of loop detector data daily. They are archiving this data and making it available on the internet, but they do not have the resources to effectively manage this data. This is valuable traffic data that the private sector could add value to and market to potential users of the data.

Information service providers can acquire this data from TransGuide, and create a database of TransGuide loop detector data. From this archived data, they would be able to predict short-term future traffic conditions and have a San Antonio traffic volume database. They could make these predictions of short-term future traffic conditions available to motorists through the internet or telephone for a fee. TransGuide could also acquire access to the database in return for supplying the data and use it to predict incidents. In the case of incidents, the data could be used to route the motorists to the most appropriate detour. The traffic volumes in the database could be sold to local contractors, local transportation consulting firms, and public agencies that have use for traffic volumes

There are several ways that the general public benefits from this partnership. First, motorists would benefit from a savings in travel time, resulting from the improved traveler information that is provided by the information service provider and TransGuide. The archival and management of data by the private sector would allow TransGuide to direct more resources towards serving the public, improving the quality of service that they provide. Finally other state agencies that would acquire traffic information from the private sector could use these resources for other purposes.

GUIDELINES FOR DEVELOPING PUBLIC/PRIVATE PARTNERSHIPS

This section of the report outlines the guidelines that public agencies must use when they are entering into a partnership with the private sector with a goal of developing a system to manage archived ITS data. These guidelines should allow the public and private sectors to create a partnership that minimizes potential financial, organizational, and legal problems that could occur down the road. The guidelines consist of the following five steps that are described in detail later.

Table 6. Guidelines for Developing Public/Private Partnerships

Step 1: Create framework for the archived ITS data system.
Step 2: Select private sector partners.
Step 3: Negotiate the contract.
Step 4: Amend differences between partners.
Step 5: Create the archived ITS data management system.

Step 1: Create framework for the archived ITS data system

A successful archived ITS data system must be able to store data, manage data, and allow users to easily access specific data. A framework must be developed to determine how these features can be achieved. Multiple public sector agencies reside over an area, so the initial partnerships will be public-public partnerships that will utilize the resources of that area. One public agency needs to take the lead and coordinate the efforts of all partners. From this agency, one project leader must oversee the entire project. This leader will need to be able to communicate with the upper management of other agencies and private sector companies. The final product of this partnership must be something that will satisfy the data needs of the potential consumers, so these consumers must be interviewed about their needs. Knowing what data and technologies are available, the lead agency must determine what product can be delivered to the consumers (14,26).

Step 2: Select private sector partners

The project leaders must evaluate potential private sector partners and determine which ones are the most compatible with the framework that was created in Step 1. The private sector partners are critical because they are familiar with the market and are able to cater to it. The private sector participants will primarily be interested in maximizing their profits, therefore, it is important to select partners that will make decisions that benefit the partnership (14,26).

Step 3: Negotiate the contract

In this step, the details of the contract should be laid out. The components of the archived data management system should be assigned to the partners, based on their strengths and interests. It is not necessary to have formal legal contracts, but at a minimum, all of the duties need to be determined in informal written agreements. The agreement should include details about which partners will be responsible for data storage, management, and access. It is also important to determine how the revenue generated from the data management system are distributed among the partners (14,26).

Step 4: Bridge differences among partners

Throughout the contract negotiation stage there will be significant differences of opinion among all of the partners. It is important to lessen the problems of partner-to-partner interactions as much as possible, so each group needs to try to understand the needs and goals of the other groups. A couple of strategies that help the communication among groups are the empowerment of key individuals and personnel exchanges. A mediator that is trusted by all parties can be appointed to translate and negotiate the needs and objectives of the participating organizations. This individual would work to resolve the differences among the groups. In addition, exchanging personnel among involved agencies allows the exchanged members to gain insight by seeing the day-to-day operations of other agencies (26).

Step 5: Create the Archived ITS Data Management System

Throughout the process of developing the data management system, the partnership should receive feedback from the users of the product. This will allow the team to develop a product that will satisfy the needs of the users. Finally, like any other product developed, a key to the success of the product will be how well the product is marketed. The partnership must determine the appropriate outlets to market the product and then market it accordingly.

CASE STUDY: SAN ANTONIO, TEXAS

San Antonio, one of four cities chosen for the Model Deployment Initiative (MDI) is the third largest metropolitan area in Texas and is the 8th largest city in the nation. TransGuide, the ATMS program in San Antonio, produces over 150 megabytes of ITS data daily and expressed interest in private sector investment in the archival of their data.

Application of Guidelines for Developing Public/Private Partnerships for Managing Archived ITS Data

This section of the report uses guidelines described earlier to implement a case study in San Antonio, Texas.

Step 1: Create framework for the archived ITS data system

San Antonio Transguide is currently involved in public/public partnerships with transportation research agencies, public transportation agencies, the police department, and the fire department. The TransGuide building is shared by the following public agencies; the Texas Department of Transportation (TxDOT), the San Antonio Police Department, the San Antonio Fire Department, VIA Metropolitan Transit, Texas Transportation Institute, and the City of San Antonio. Each of these agencies benefits from the real-time traffic information that TransGuide provides.

Transguide has installed 590 in-vehicle navigation units (IVN) in law enforcement, fire, and public transportation vehicles. They use Global Positioning Satellite signals to identify exactly where the vehicle is located, which can help guide airlift helicopters or other emergency vehicles to accident sites. TransGuide can also use these IVN units to offer alternative routes to the destination, show the route with highlighted map segments, and notify the driver when to turn or if the car is off the route. Transguide also has two-way video, audio, and data teleconferencing links between hospitals and EMS units. These links allow doctors to monitor vital signs of patients by actually seeing the patients and talking to paramedics. TransGuide also disseminates real-time traffic information on their internet website.

With access to an archived ITS database, TransGuide could use the historical data to track trends in their transportation system and predict future traffic conditions in the short-term. By tracking trends in their

operations, TransGuide would be able to determine how well their system is performing on a day-to-day basis. This would make it easier for them to determine which parts of their traffic operations needs improvement and help them make adjustments. By predicting future traffic conditions in the short-term TransGuide would be able to predict more efficient routes on their changeable message signs, IVN units, and webpage.

TxDOT coordinates the other agencies in the TransGuide real-time operations, so they should also serve as the lead agency in the archived data partnership, also. This data partnership will be comprised of all the agencies that occupy the TransGuide building because each of these agencies will receive great benefit from using the archived data.

TTI's Translink[®] research program has an "ITS Data Management" focus area, in which Translink[®] personnel have developed Datalink, a prototype on-line ITS data management system. The Datalink system warehouses data from TransGuide loop detectors that are aggregated into 5-minute intervals. The 5-minute intervals were chosen based on user data requirements and database performance. This database is a 40+ gigabyte relational database, where users can access the data using a web browser interface. In the public/private partnership, the loop detector data will be archived in a similar manner that it is currently being archived. A similar system will have to be set up to archive the AVI data (6).

Step 2: Select private sector partners

TxDOT will search for private sector companies that could benefit from joining the archived ITS data management system public/private partnership. Local information service providers that could potentially increase their business with access to archived data would have to be educated on the potential benefits. TxDOT could market the idea to local transportation agencies.

Step 3: Negotiate the contract

In this step, the specifics of the archived ITS data management system are partitioned among the partners. The partners located in the TransGuide building will be responsible for providing and maintaining the computer equipment. The private sector partners will assess the market and determine the technical details of the service. These details for the loop detector system would include modifying the Datalink system to meet the needs of the potential users. A similar system would have to be designed by the private sector for the AVI data. TransGuide would retain the ownership rights to the data, with the private sector having unlimited access to it. The ownership of intellectual property rights of the algorithms and software developed would be an issue that would depend on exactly what the private sector develops.

Step 4: Amend differences among partners

There should not be any major problems among the public sector partners, since these groups have been working together at TransGuide for years. There may be problems with the public/private relationships because of the general differences between the two sectors, especially the differing goals and motivations between the two groups. Somebody in the TxDOT organization will have to step forward and coordinate the efforts of the two sectors.

Step 5: Create the archived ITS data management system

Throughout the developmental process the private sector should be determining the needs of the users and designing a product that caters to their needs. The data should be available in the least aggregated form the market desires, and users should also be able to aggregate the data to the level that satisfies their needs. This product should be marketed to transportation professionals and other potential users throughout the San Antonio metropolitan area.

CONCLUSIONS

Every day, there are large quantities of valuable ITS data produced throughout the United States for real-time traffic information purposes. These data have many applications other than real-time purposes, but if the data are not properly archived, valuable traffic information is wasted. It can be costly to archive this data, so the permanent archival of this data may only be possible through the formation of public/private partnerships. The public sector has the infrastructure, and the private sector has the knowledge of the market. This combination allows the private sector to add value to the public sector data, such that it is more attractive to consumers.

There are also many potential problems that could result from the development of archived ITS data public/private partnerships. Since archived ITS data has never been marketed to the public, the potential for making profit from the sale of the data is unknown. Also, the public sector is concerned about allowing too much information to cross their firewall. The various end users of the data have varying needs for the data, so it may not be feasible to accommodate all of these needs.

The guidelines developed in this report provide recommendations for the development of a public private partnership to create an archived ITS data management system. These guidelines serve as guidelines for overcoming some of the barriers that exist due to the differences in the public and private sectors. These guidelines are flexible so that they can be applied to different geographic regions and different types of public/private partnerships.

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**SIMPLIFYING DATA ENTRY FOR ROADWAY
AND PAVEMENT CONDITION INFORMATION SYSTEMS**

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SUMMARY

With the increasing popularity of home computers and the ease with which one can access the Internet, motorists can look up travel information from the comfort of their own home. Many states have some form of road condition advisory available on the Internet now. It seems like the perfect way of providing important information for the motorists, who can access it when they want, at relatively low cost.

For a motorist to take advantage of this information, it must be current and relevant to the individual. Anytime these criteria are not met the user loses confidence in the system. For the Texas Department of Transportation (TxDOT), it has been determined that a lack of time coupled with a complex data entry and retrieval system is a primary cause of this type of problem, non-current information.

A literature review was conducted to determine the current practice in developing a data entry application of this type. The guidelines presented in this paper are summarized from the literature reviewed. Also, a survey was conducted of other state DOTs to determine how their road condition data entry systems operated and how the information is presented to the motorist. A survey of transportation individuals in the San Antonio district of TxDOT was also conducted to aid in the evaluation of the current system and to determine any specific needs they might have.

This report contains guidelines for the development of a graphically based data entry system that is designed to save time and make road condition data entry easier. It is believed that with the aid of this new system, those responsible for entering the information will be able to do so more frequently, reducing the problem of non-current data. These guidelines are then used to develop a preliminary prototype that is compared with the current system.

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INTRODUCTION

Currently in the State of Texas, motorists can use the Internet or the telephone to contact the Texas Department of Transportation (TxDOT) for information regarding weather conditions on roads throughout the state. The parties that are primarily responsible for providing this information are not always able to report it in a timely manner and as consequence the information is sometimes not accurate. These inaccuracies can cause the public to lose confidence and no longer seek the information.

Problem Statement

It is believed that the problem lies in the current system that is used to enter the information. The system is text based and requires a fair amount of time to enter the data (*L*). Oftentimes, those who are responsible for entering the data (usually the maintenance supervisor for that area) simply do not have the time to enter new data on a regular basis, especially when they are coping with a weather or roadway emergency. It is believed that if the system could be simplified, it would allow the maintenance supervisor to enter the data quickly and more frequently. This in turn would help keep the information current and ensure motorist confidence in the system.

Objectives

There are four primary objectives to this study. These are to:

- Examine and evaluate the current system from data entry to public access;
- Determine what technology or information is available that can be used to improve the current system;
- Using the information obtained in the previous objective, develop a set of guidelines for the development of a prototype system; and
- Develop sample prototype based on guidelines.

Report Organization

There are six main sections to this report. This section contains an overview of the problem and details the objectives of this study. The next section contains the methodology behind the study. Section 3 contains background information and details the results of the literature and technological review, while the fourth section contains the survey results.

The fifth section uses the information from the previous four sections to develop a specific set of guidelines for the development of a new data entry system. Finally, section 6 contains an initial prototype design that is based upon the information presented throughout this report.

STUDY METHOD

Evaluate Current System

This is the first and an important step in the development of a new system. The evaluation of the current system will provide insight to its weaknesses and strengths. The evaluation will be accomplished by interviewing those who work with the system, the maintenance supervisor survey, and a hands-on evaluation.

Literature Review

The purpose of the literature review was to determine the current practice in human-computer interface systems. The search for related information was divided into two categories, transportation and human factors. The results of this review are presented as background information in the next section.

Data Collection

Data collection took two forms. First, a review of other state's road condition information systems on the Internet was performed. Individuals who participate in upkeep of these systems were contacted in an effort to determine how data is entered into the system. The selected states consisted of Utah, Oregon, Virginia, Maryland and Pennsylvania.

The first step in this process was to examine the road condition information Internet site maintained by each state. Individuals involved were contacted and asked questions focused on how information was entered into the system and who was responsible for entering it. Using this information, each system was compared to the system used by TxDOT.

The second part of the data collection process consisted of surveying area maintenance supervisors of TxDOT to gain greater understanding of the current system and the limitations of it. A secondary purpose of this information was to validate the original theory that the current system is cumbersome (1). Items of interest from the survey were:

- Who collects the data and how is it collected?
- Who enters the data into the system?
- How often is the data updated?
- How hard is it to enter the data?
- What would make the process simpler?
- Would a simpler process affect the frequency of data entry?

A copy of the survey that was administered appears in the appendix.

Analysis and Application

The analysis portion of the paper consisted of taking the information acquired from the literature review and the surveys and developing guidelines for the prototyping of a new data entry system. Using these guidelines, a trial prototype was developed. The trial prototype was then compared to the existing system detailing what improvements would be made.

BACKGROUND

Human-Computer Interface Guidelines

If a new system or application is going to be used for the entry of road condition data, it should follow certain guidelines. These guidelines have been developed over a period of many years by human-factors and human-computer interface (HCI) researchers. Since the development of the first cathode-ray tube (CRT), human-computer interaction techniques have been studied (2). The following section contains an overview of some general guidelines.

Consistency

This may be the most important guideline given. Interactive control actions should be consistent in form and consequences from one task to another (3). Consistency in the data entry format allows users to develop a mental model of how the system works, thereby reducing human error rates and the amount of training required (3, 4). Consistency includes the wording of messages, placement of action buttons, even the color scheme used.

The best way to obtain consistency is to develop a set of design standards from the start. There are industry standards already available from IBM (1993) and Microsoft (1995) which help define many of the needs (95 to 99 percent) of the designer. Which industry standard the designer uses should be based on what operating system, i.e. Windows 95®, is being used. Any remaining holes in the design standard can be filled at the designer's discretion.

If consistency and design standards are used, users of the data entry system will most likely have prior knowledge of how to work the data entry system. Consistency between applications and tasks means the rules of operation do not need to be repeated, nor is there a need for great detail in explaining the use of each and every feature (4). Use of the system quickly becomes second nature.

Simplicity

Simplicity is a characteristic of good design. As a general rule, the data entry program should not be more complex than is needed. Excessively busy displays (overall density greater than 40 percent) are difficult to understand and consequently difficult to use (4). Colors should be used sparingly and consistently throughout the application and follow the contrast rule, light on dark or dark on light.

The designer is encouraged to use fonts that are easy to read. Use of more than two to three different fonts on a particular screen should be avoided, keeping in mind that a change in size, style (bold, italics, underlining, etc.), and colors constitutes a different font. Following these rules will yield a simpler and easier data entry system.

Associated items, such as road condition classifications, should be grouped together while keeping unassociated items separate. Actions should occur in the areas where the user is working and should follow a logical order. Data entry tasks should be able to be completed with a minimum number of actions and should not require repetitive entry of information (3).

User Issues

Given the variability in users, the data entry system should support both novice and expert users. This entails allowing users to modify some options of the system according to their needs. As novices learn to use the data entry program, they can explore the more advanced options. The use of program functions that are available only by clicking a certain item or area should be avoided. This is called hidden functionality and can prevent users from gaining experience in the operation of the data entry system.

It is common practice to define a default button on every screen. The default button is invoked if the Enter/Return key is pressed. Oftentimes, users will unintentionally hit the Enter/Return key actuating the default function. For this reason, the default button should not be associated with a potentially destructive function, such as the deletion of information.

Other user related issues include keeping short-term memory requirements of the user to a minimum. This can be accomplished by using appropriate displays and making interactive sequences self-evident. Also, the names of control functions should be semantically congruent with normal usage, i.e. **Up** goes with **Down**, not **Lower** (3).

Prompts and Feedback

The purpose of prompts is to obtain required information from the user and provide orientation of the computer's processes. Prompts should be clearly displayed in a consistent location, indicate what information is expected, and remain visible until appropriate action is taken. It is desirable that users have the ability to control the level of prompting detail.

Feedback is an important part of the data entry system. Feedback includes any message that is generated by the computer for the user and can take the form of sounds, actions or the actual display of a message. This may include routine messages, error messages, or user-requested messages. Also, if a requested operation takes more than two seconds to process, the system should provide feedback in the form of a "working" indicator or a message. For extra long processing times, feedback should be given upon the completion of the task (3).

Error Management

Errors will occur from time to time and mechanisms for dealing with them need to be available. User errors should be displayed as quickly as possible allowing the user to correct the problem immediately. Where possible, options for correct input should be displayed. Also, if an error occurs during the execution of a multi-step function, users should be able to correct the error without having to repeat the whole process.

Prototype Development

Prototyping is an iterative analysis technique in which users are actively involved in the design of the user interface. Through the solicitation of user input, the designer can avoid costly errors in the application.

Prototyping Steps

The first step is to determine the needs of the user. These requirements can be gathered in a number of ways including interviews or modeling sessions. Once the uses are determined the prototype is built and evaluated. The main goal of the evaluation step is to verify that the prototype meets the needs of the users. Once the evaluation is complete, the designer needs to determine if the prototype is complete. Figure 1 is a simple flow chart diagramming these four steps.

Tips and Techniques

For prototyping to be successful, it is essential to use the actual users, in this case the area supervisors and office personnel, for the evaluation and to get them to work with it. Set a schedule to get together with the users/testers. Use interface flow diagrams, which offer a high-level view of the relationships and interactions between the interface objects.

Use a prototyping tool to help minimize the time needed to make adjustments to the prototype. Begin by using a hand-drawn prototype. Move to one that shows the screens without data and then one with data. By using this process, less time will be wasted in the early stages where changes are frequent (4).

Evaluation

The interface between humans and computers is highly complex. Given this complexity, and the fact the user interface developers are also human, there are bound to be errors. Therefore, the evaluation of these interfaces is a critical part of the design process. The sooner a problem is discovered, the less it will cost to fix it.

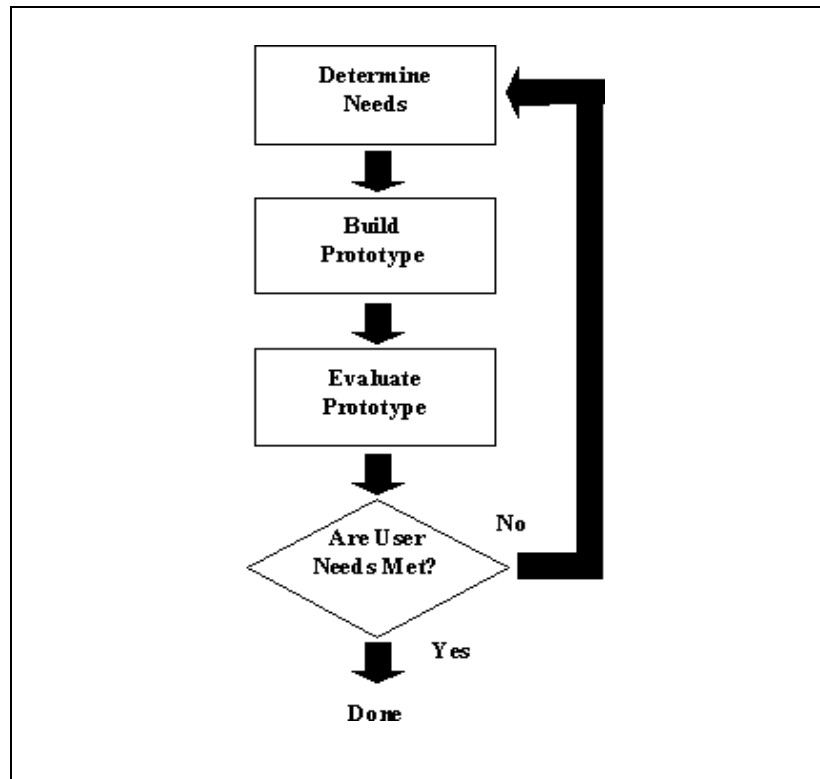


Figure 1. Prototype Design Flow Chart

Evaluation of user interface systems requires the acquisition of data on the interface in question. Because it is not possible to cover all contingencies, data are collected by taking samples (5). Once collected, the data must be analyzed so the results can be summarized. The conclusions are then fed back into the design loop so improvements can be made.

The methods for collecting data on user interfaces are numerous. Specific types include personal interviews and questionnaires, the collection of protocols (such as think-aloud or video), or the program may be designed to collect data on its own. The method used will depend on the details of the interface, such as, how often it is used or for how long (5).

SURVEY RESULTS

State Departments of Transportation

Part of the process of this survey was to examine the road condition information that each of the six states made available on the Internet. The primary purpose of this survey was to a point of contact in that state's DOT. Once the point of contact was determined, e-mail messages were sent, requesting information on how data were entered into the system and who was responsible for its entry. Another purpose was to compare the other states Internet information with that of Texas.

From the study of the Internet, it was determined that each of the six states offered some form of road and pavement condition information, including information about construction areas, road closures due to severe weather, traffic reports, and detour information. All six states offered this information through the Internet. In all cases, information about weather related road conditions was provided on a seasonal basis.

Virginia, Pennsylvania, Maryland and Oregon primarily used graphics, in the form of color-coded maps, for informing motorists of road conditions. Figure 2 is a sample of the system used by Pennsylvania. The major routes are shown on the map and are color-coded to indicate their condition. On this sample the colors have been replaced by different shades of gray. The other three states had similar setups to Pennsylvania.

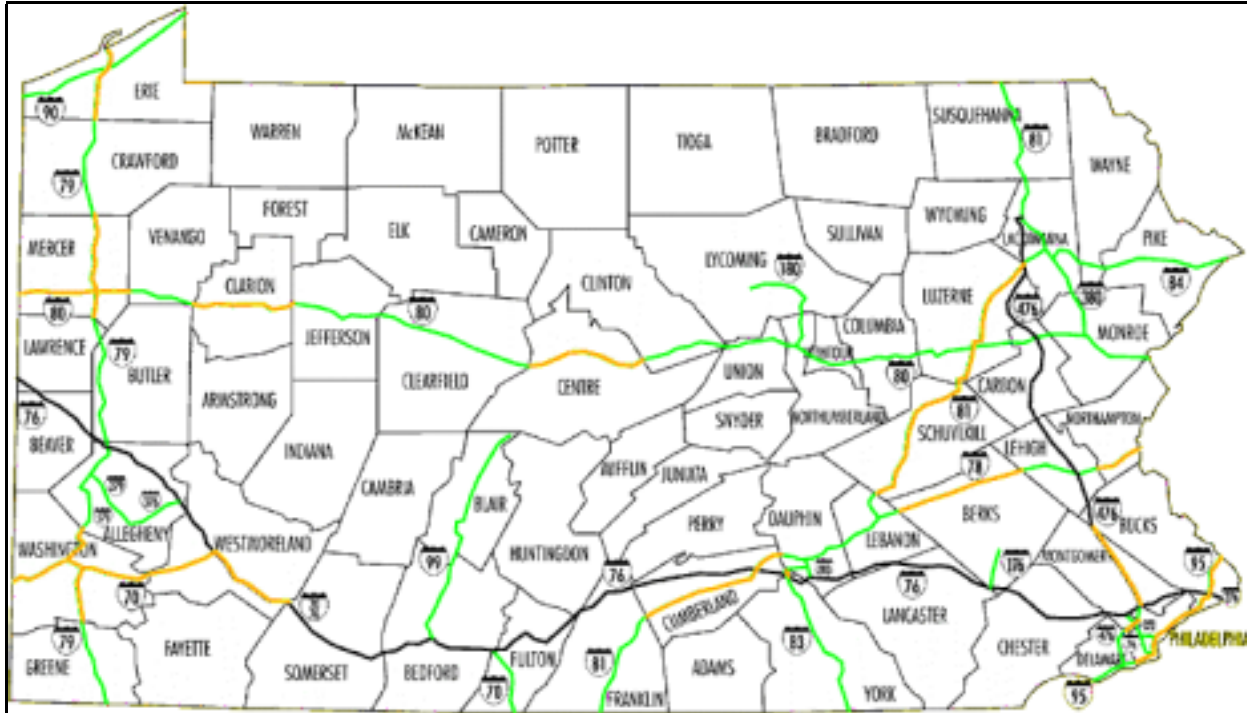


Figure 2. Road Conditions Information Page for Pennsylvania

Virginia

From the five states surveyed, the only response came from the State of Virginia. To better understand how the road condition information system works, the hierarchy of the Virginia Department of Transportation (VDOT) needs to be explained. Basically, Area Headquarters report to the Residency, the Residency reports to the District, which then reports to the Central Office. The Transportation Emergency Operations Center (TEOC) is located at the central office and is responsible for receiving, analyzing, and disseminating all incident data it receives (6).

All road condition information is transmitted through the Virginia Operational Information System (VIOS) which allows many state agencies to share the information. Road condition information can be input at any level, but usually begins with the Residency. The Residency supervisor enters condition information that is then translated into one of the 5 color codes used by VDOT. Once the information is entered, it immediately becomes available over the whole system (6).

From the information provided, it appears that there are three simple steps involved in entering the information. They are, selection of the road in question, specify a section of that road, entry of a condition for selected section. It was unclear if these steps were accomplished using keyboard commands (text) or by pointing and clicking with a mouse (graphical).

In contrast, both the Texas and Utah systems were primarily text based. In the case of Utah's system, the state is divided into five regions. When a motorist enter the road condition information section, they

are instructed to select a region. Upon selecting a region, the motor is presented with a list of roads and their current condition for the entire region. It is then the responsibility of the motorist to find the road of interest.

Texas

TxDOT’s system is setup very similarly to that of Utah’s. When an individual first enters the road conditions page, a map of the state is presented with several little blue (dark gray) boxes covering it (see Figure 3). Each blue box represents an area for which road condition information is available. To access this information, motorists select the square nearest to the area of interest.

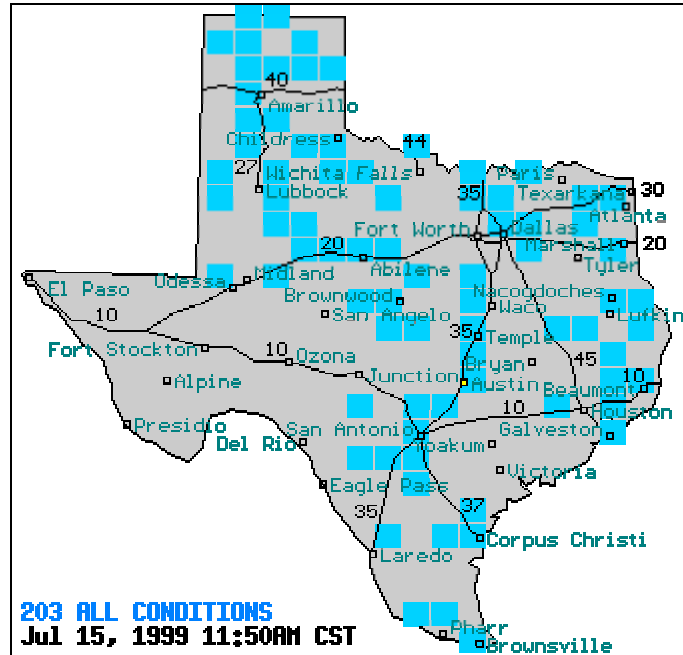


Figure 3. Texas Road Conditions Sample Map

After selecting an area, road conditions for the entire area are then presented in text format as is shown in Figure 4. Note that Figure 4 is only a short listing and that in most cases there were more than a dozen listings for a selected area. Given these multiple listings, the motorist was required to scroll through the available information to find the roadway in question.

For Texas, the entry of road condition data begins at the area level. Each area office acquires road condition information through a variety of sources. It is the responsibility of the area supervisors to see that these conditions are reported to the central office in Austin, where the data are entered into the road conditions web page and made available to the public. This process is detailed later in this report.

Area Supervisor Survey

The purpose of the survey was to gain a better understanding of the data entry system used by TxDOT and its associated limitations. Coupled with the results of this survey, is a review from a first-hand look by the author and an accompanying interview of a TxDOT employee. It was believed that the responses could have bias because the maintenance supervisor’s fear of possible reprisal for criticizing the system, so the survey data were collected in such a way to promote anonymity.

Interstate 410 OTHER DELAY in Bexar County

N-S-bound from US 90 INTERCHANGE to US 90 INTERCHANGE

JULY 17-18, SAT.-SUN., 7:30AM-4PM, FOR THERMOPLASTIC WORK. NO LANES CLOSED, BUT TRAFFIC WILL MOVE VERY SLOWLY.

(Texas Travel Map 15-R, San Antonio District, Jul 15, 1999 7:21AM CST)

Interstate 410 CONSTRUCTION DELAY in Bexar County

S-bound from CULEBRA RD. to US 90

ALT. LANE & RAMP CLOSURES 7-26 THRU 8-6, 10PM-5:30AM, SUN. THRU THURS. ALL LANES CLOSED AT MIDNIGHT. USE ACCESS RD.

(Texas Travel Map 15-R, San Antonio District, Jul 31, 1999 6:57AM CST)

Interstate 410 CONSTRUCTION DETOUR DELAY in Bexar County

N-S-bound from N. OF US 87 to S. OF SOUTHCROSS

SB DETOUR TO NB. NB 1 LANE OPEN. NO LOADS OVER 9FT. WIDE. SB WIDE LOADS MUST EXIT RIGSBY. NB WIDE LOADS EXIT SOUTHCROSS.

(Texas Travel Map 15-R, San Antonio District, Jul 31, 1999 6:57AM CST)

Figure 4. Sample Text of Road Condition Information (Texas)

There were a total of 15 responses to the survey. Most of the responses came from area supervisors, but a couple of the responses came from individuals who work in the area offices. The first five questions were designed to provide insight into the operation of the system. The sixth question asked individuals to rate the system's ease of use. The last two questions were posed in an effort to determine possible changes that would be beneficial to the system.

Table 1 contains a summary of the results. The first column lists the question asked. The second column indicates possible responses, with the third column listing the percentage associated with each response. Answers to the fourth and fifth questions were not limited to one response, so percentages do not total to 100 percent.

Data Collection and Entry

Road condition data is collected by a combination of crew observation and the law enforcement, which includes both local and Highway Patrol. The primary collector of this data is the maintenance supervisor of the area with the crew providing additional help from time to time. The majority of those questioned indicated that the supervisor was the responsible for overseeing data entry, but 27 percent indicated that another party would sometimes enter data.

Comparison of the survey results and information acquired during the interview revealed what appeared to be an inconsistency. In practice, it is very rare that the area supervisor will enter road condition data. This responsibility typically falls to an office assistant who is at the area office throughout the day (Z). Thus, it appears that the area supervisors feel they are directly responsible for the entry of the data, but delegate the responsibility as necessary.

Answers to the fourth question were not limited to a single answer. Nearly half of those questioned entered road condition data on a daily basis, while only 13 percent updated it every 2-4 hours. But, three-quarters stated that they enter data based on need, which indicates that many will engage in more frequent updating when necessary.

Table 1. Survey Results Summary (15 responses)

Survey Question	Responses	Percent
How is data relating to road conditions collected?	Law Enforcement	-
	Crew Observation	-
	Combination of Both	100
Who collects the data?	Maintenance Supervisor	60
	Maintenance Crew	33
	Other	7
Who is responsible for entering the data?	Maintenance Supervisor	73
	Other	27
How often is the data entered/updated?	Hourly	-
	Every 2-4 Hours	13
	Daily	47
	Need Based	73
How often should the data be updated?	Hourly	-
	Every 2-4 Hours	27
	Daily	73
	Need Based	60
How do you rate the current system used for entering and transmitting the data?	Easy	-
	Fairly Easy	13
	Fairly Hard	47
	Hard	40
What do think would simply your data entry?	Graphical Interface (no text)	20
	Graphical Interface (with text)	13
	Do Not Know	67
Do you believe that a simpler entry format would promote more frequent updating?	Yes	40
	No	13
	Do Not Know	47

The fifth question asked how often the road condition data should be updated. 27 percent stated that it should updated every 2-4 hours, while 73 percent stated daily is minimum requirement. In fact, the system requires the information to updated daily. If it is not, it is deleted from the system (Z). This helps to ensure non-current information does not remain in the system due to oversight.

Again multiple responses to the question were allowed. The result is that 60 percent of those questioned indicated that data should be updated whenever need dictates. It is interesting to note that this 60 percent came from the 73 percent stating a daily updating is the minimum. Given these results, it appears that the majority (87 percent) of those responsible for entering the data understand the importance of keeping the data current.

Data Entry and Retrieval

Frequent entry of road condition data appears to be a desire among those responsible for it, but given the results of the sixth question, the data entry system does not appear facilitate this. Referring again to Table 1, it can be seen that an overwhelming majority rated the system as hard or very hard. The results of the survey appeared to be in conflict with information from the interview and first-hand evaluation.

Data entry begins by logging into the system. The operator then designates a roadway for which information will be entered by typing its name. Next, the affected section is specified and finally, a

condition is specified by entering a numeric code from a predetermined list. The operator is also given the option of enter more detailed information for the affected section. Once these steps are complete, the information is immediately made available to the entire network.

The three steps do not appear to be very complex to someone who is familiar with the system. But, for those unfamiliar with it, it becomes a complex system in which one can get lost (8). From the survey, it was noted that the two responses indicating the system was fairly easy to use did not come from area supervisors, but office workers. Apparently, familiarity with the system directly affects one's assessment of it.

Even though the system is not complicated, data entry still takes time. The text-based entry of data into the system can be a disadvantage at times when frequent updating is necessary. An example of this is severe weather conditions that change frequently throughout the day (Z). A graphically based system that requires three clicks with a mouse to accomplish the same steps would greatly reduce the time required for data entry.

The true weakness of the current system is not in the data entry portion, but the in the retrieval of the data. As was indicated motorists can call either the TxDOT Hotline or a local maintenance office to acquire information about road conditions throughout the state. This requires the operator of the system to scan through multiple areas that contain lists similar to those of Figure 4. This is very time consuming and inefficient compared to a graphical system that would have statewide conditions at a glance.

Improvements

The final two questions were designed to explore improvements to the system. Question 7 was designed to gain feedback in what would make the system simpler. One-third of those surveyed indicated that a graphically based data entry system (with or without text) would be simpler, but nearly two-thirds indicated they did not know what would make the system simpler. The final question was split with almost half saying a simpler format would increase entry frequency, while the other half was unsure of the benefits.

Although the survey does not overwhelmingly indicate the need for improvements, individual interviews did. Many of the problems have already been presented and possible solutions given, but more discussion is warranted. The next section contains the development of preliminary prototype and compares the existing system with the proposed improvements.

PROTOTYPE DEVELOPMENT GUIDELINES

Determine User Needs

The most basic needs of the user that have already been identified are:

- Data entry and retrieval system is simple to use.
- Move from the text based system to one that is graphically based.
- Program should be easy to learn.

The needs specified are generalizations for the group as a whole. To make the system even more effective the needs of each individual should be addressed. This is accomplished by seeking input from the end user, in this case the maintenance supervisor. Methods for obtaining these data include surveys, interviews or hands-on observation.

It is impractical to develop an application for each individual supervisor. But, with specific input from them, it is possible to develop user-defined options and functions that allow for individualization. Supervisors and office personnel should be involved from the earliest stages of the design process to maximize the benefits of user input.

Initial Prototype Design

The first step in the development of a prototype is to create an interface-flow diagram. The purpose of these diagrams is to provide the designer with a greater understanding of how the system is to work. Also, by sketching out the initial design in a crude manner for review by the user, specific needs can be assessed with a minimum of work. Figure 5 is a representation of what the initial interface flow diagram might look for this project.

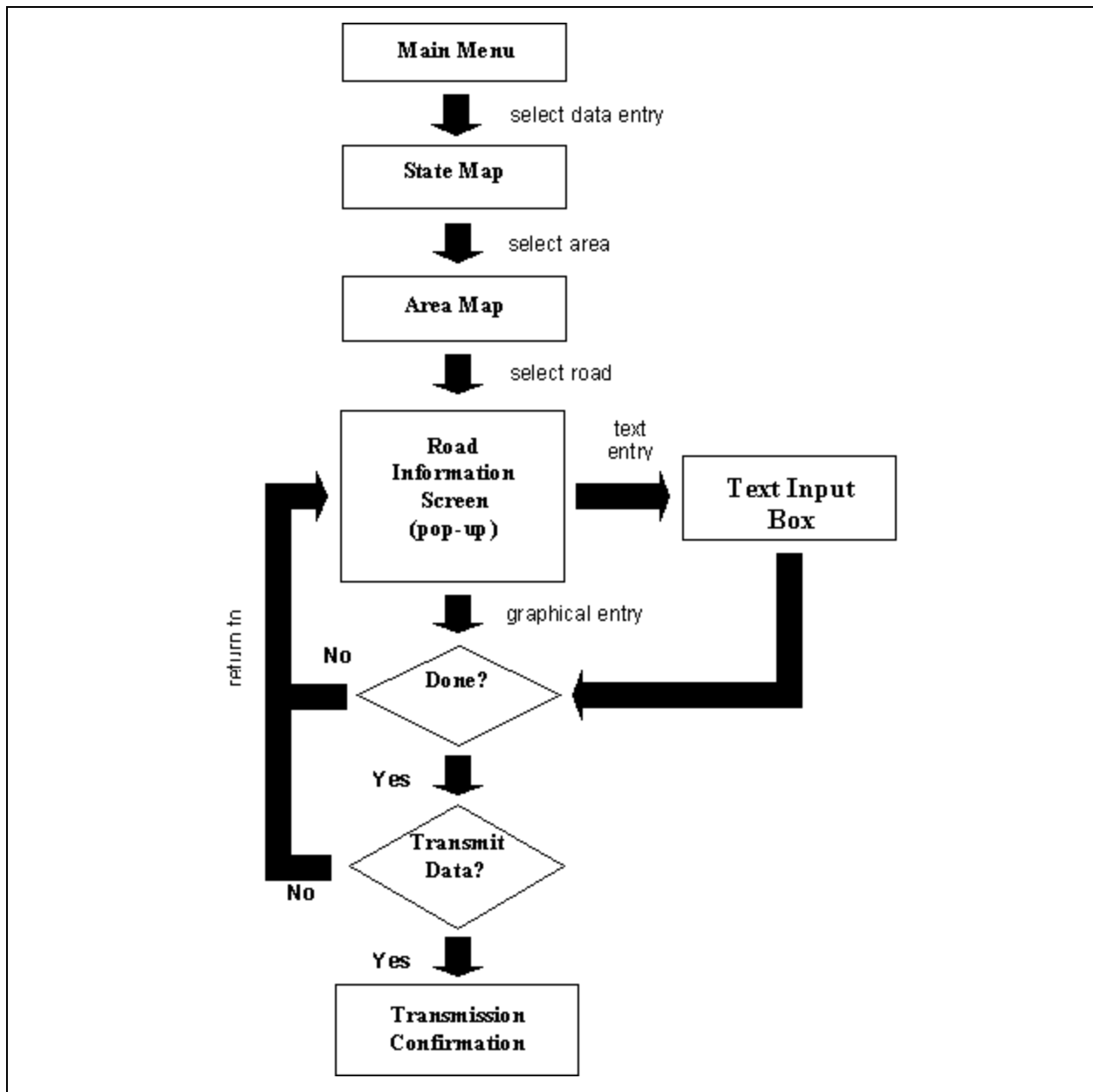


Figure 5. Sample Interface-Flow Diagram

From the main menu, the supervisor would enter the data entry application. Here they would be presented with a map of the state from which a specific area could be selected. Upon selection of an area, a new map would appear displaying the roads of that area. Supervisors then select a road or section of road to enter condition information.

Upon selection of a section of roadway, a pop-up window would open with the options to input a general condition class for the section or to enter text information about the section. If the supervisor desires to input text another pop-up box would appear for text input. From here, they can return to the selected road's information screen or go back to the area map to select another road.

Once the supervisor is finished entering the data they can transmit the data to the central area for posting on the web. Upon transmitting, there would be a confirmation of the transmission. At this point the supervisor would be taken back to the main menu. This is a simple representation, but it illustrates the basic process.

Prototype Evaluation

Once the initial design is complete, testing of the prototype can begin. There are a number of ways to evaluate the design. One such way is to have a supervisor actually enter information in the prototype and evaluate its performance. Possible questions include:

- Was navigation through the program difficult?
- Was the information presented in a logical form and easy to understand?
- Do you believe the information entered was sufficient for the motorist to understand? Why or why not?
- How long did it take to enter the information? Did it take less time than the current system?

There are many more questions that could be asked, but the most important thing is to make sure the users' needs are addressed. Knowing what the user thinks about the product goes a long way to seeing if it meets their needs. If the needs of the supervisor are not met, then the whole process begins again incorporating the new information obtained during the evaluation.

SAMPLE PROTOTYPE DEVELOPMENT

This section contains the development of a new data entry system based on the interface-flow diagram shown in Figure 5 and guidelines discussed in both the background and previous section. Differences between the proposed and current system will be highlighted and discussed. The discussion of users' needs and prototype evaluation have been presented in previous sections and will not be covered here.

Referring to Figure 5, the likely place to begin would be just after the user elects to run the data entry program. This would bring the user to a map of the State of Texas that would be broken into sections or districts such as those shown in Figure 6 below. The next step is for a user to select a district in which data are to be entered.

A new screen would be presented providing greater detail of the area in question. All major roadways through the area would be shown. An example of how the section would look can be seen in Figure 7. In this screen the user would select a section of roadway for which information is going to be entered.

The issue of determining roadway sections needs to be addressed. In the current system, sections are designated by entering text to describe the section affected. In the new system, major highway intersections or towns could be used to define sections. Further study is needed to resolve the issue.

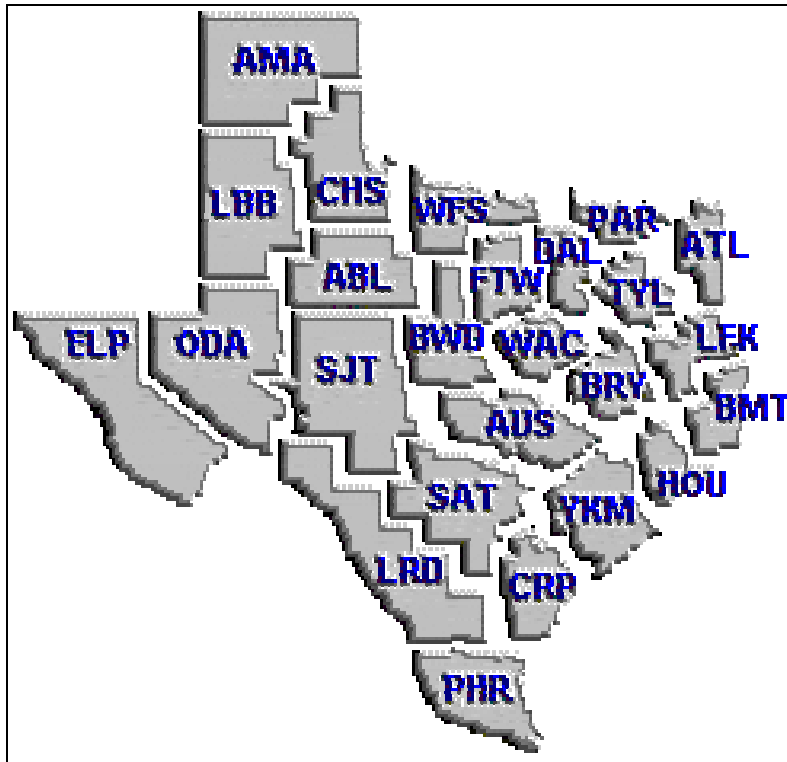


Figure 6. Sample Map of TxDOT Districts (9)



Figure 7. Sample Area Map

Once the section of roadway is selected a new window would appear, overlaying the area map requesting the input of information. The new window would contain the name of the road and several condition options. The user would then select a condition by clicking on it. A sample layout of this screen can be seen in below in Figure 8.

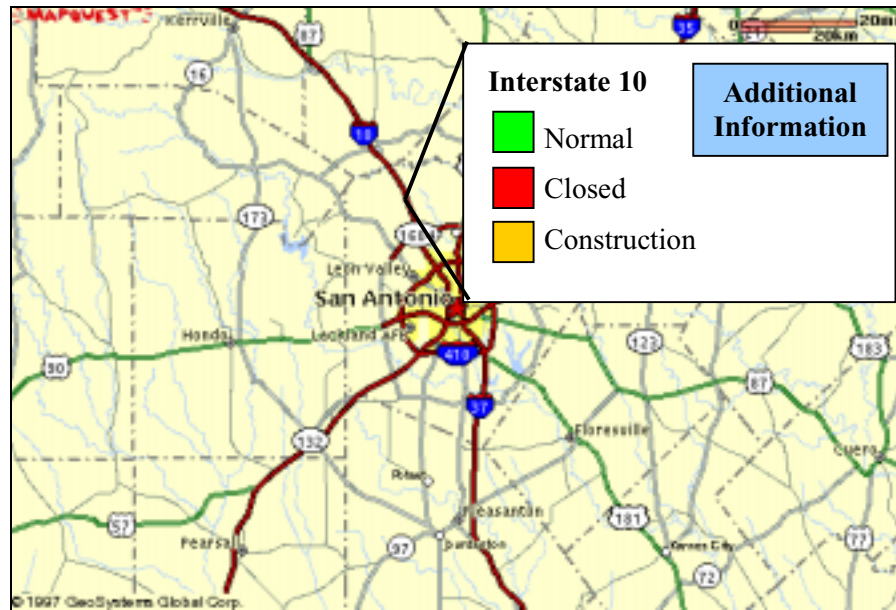


Figure 8. Sample Road Condition Input Screen

Included in this screen would be an option to enter any additional information the user may feel is necessary to clarify conditions. By selecting the additional information button, a text-input box would appear. Also, at any time, the user could return to any of the previous screens through commands available on the menu bar. Once finished, the user can close out of the data entry system, which will activate an update feature making the new information available across the system.

CONCLUSIONS

From the survey of the area maintenance supervisors it is evident that there are failings in the current system. Time consuming data entry and complex data retrieval are preventing the system operators from providing current information to the motorist. It appears that by improving the way road condition data is entered into and accessed from the system many of these problems could be limited or possibly eliminated.

The development of a new data entry system would be based upon the steps of determining the user's needs, development of a prototype, and evaluation of this prototype. These steps are performed in a loop fashion incorporating the results of the evaluation into the design. Prototype development is based upon several guidelines, such as consistency in the design and use of industry standards, simplicity of use and design, and error management.

Clearly, there are other issues that need to be examined. One issue that could be developed further is the use of mobile computers, both laptop and handheld. No matter what the focus is, the weak link of the system is the human factor. If the need for human interaction can be minimized or removed, then the system should operate more efficiently and with less error.

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APPENDIX

Sample Questionnaire

- 1) How is data relating to weather and road conditions collected?
- 2) Who collects the data?
- 3) Who is responsible for entering the data?
- 4) How often is this data entered or updated?
- 5) How often should the data be updated?
- 6) How would you rate the system used for entering and transmitting the data?
(easy, fairly easily, fairly hard, hard)
- 7) What do you feel would simplify you data entry?
- 8) Do you feel that simpler entry format would allow to update the information more frequently?



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**DEVELOPMENT OF PLANS TO USE ITS TECHNOLOGIES TO FACILITATE
TRAFFIC AFTER SPECIAL EVENTS**

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SUMMARY

This paper contains the review of plans to facilitate exiting traffic at special events such as concerts, fairs, and sporting events. These special events traffic plans are either in existence or in development in various locations across the United States. This review was accomplished by the use of a survey questionnaire completed by mail, e-mail, fax, or telephone interview. Where applicable, reports or other documentation were used to supplement these surveys. After the survey results were compiled, those results were used to identify priorities, tactics, and strategies used by the various government agencies and private groups in the development of their special events traffic plans. The similarities between those priorities, tactics, and strategies were compared and discussed. Also, where applicable, the relative successes of tactics and strategies were compared. In situations where changes or modifications have been made to the original plan, the success of those changes was also evaluated. Based on the success of the various strategies indicated by survey participants, a list of recommendations was created as suggestions to aid in the development of future plans to facilitate special events traffic. To illustrate the effectiveness of these recommendations, they were used in a case study to devise a strategy to expedite special events traffic at the Astrodome in Houston, Texas.

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INTRODUCTION

Background

Special events such as concerts, fairs, and sporting events draw large numbers of people every year. Because of the large attendance at many of these events, they often have a tendency to create traffic problems for travelers during times when these events take place. These problems affect not only those who attend such events, but also others who may be simply traveling through the area at the time. Traffic engineers and law enforcement officials in many cities and urban areas across the country are examining new solutions to these traffic problems, and an increasing number are using ITS program applications with existing infrastructure to manage special events traffic. ITS program applications can be used in several ways: on a small scale to provide a fine-tuning improvement to current conditions in specific locations; on a larger scale as part of a plan to prepare for projected growth and congestion in a community; or on a massive scale as a separate project to manage a freeway corridor and the additional traffic generated by the surrounding area events.

Problem Statement

While there is often a great attempt to provide the means for traffic to arrive before events, there is not always as much effort taken to facilitate the movement of traffic after the events are over. As a result, post-event traffic can generate significant congestion on the transportation system surrounding the event venue. This increases the delay and frustration experienced by motorists in the area. If weather or an incident affects the venue area, the problem is compounded. However, the vast majority of special events are scheduled well in advance and expected traffic related to those events is somewhat predictable. If this is taken into consideration and used in a positive way, proper planning can significantly reduce congestion and increase the efficiency of the flow of exiting traffic.

The purpose of this paper is to provide recommendations to aid cities, counties, and other entities in the development of strategic plans to facilitate the movement of traffic after special events. All of the special events under consideration are based at fixed locations, such as stadiums, multipurpose arenas, or fairgrounds.

Objectives

There are six objectives in this paper. Each objective builds on the efforts of the previous objectives, with the first four objectives consisting primarily of collection of information. The fifth and sixth objectives use that information to produce a final product.

1. Examine existing plans used to facilitate exiting special events traffic.
2. Determine priorities used in the creation of the existing plans in Objective 1.
3. Identify ITS solutions currently used to satisfy the priorities in Objective 2 in order to gain an indication of possible trends and successful applications.
4. Where possible, examine results of existing plans, as well as modifications and improvements made to those plans, to identify effective solutions and changes.
5. Based on the priorities, solutions, and results from Objectives 2, 3, and 4, provide recommendations for the development of future special events traffic plans.
6. Apply the recommendations from Objective 5 in a case study of a location with significant and varying special events traffic.

Scope

The scope of this paper consists of plans and strategies used by various government agencies and private groups to expedite the flow of traffic from special events. Those plans and strategies include the examination of the nature of special events, priorities and corresponding solutions in facilitating traffic, enforcement issues, use of Traffic Management Centers, primary exit routes and modes, effectiveness of existing plans and strategies, and length of time that the plans have been implemented.

Study Methodology

1. Develop Survey Questionnaire

The primary source of information for this paper is a variety of government agencies and private organizations that have influence on the development of plans in their city or area to expedite the flow of traffic after special events at a specific venue. In order to obtain the same types of information from each agency, a standard list of questions was necessary. This list of questions is provided in the appendix.

2. Contact Agencies to Complete Survey and Provide Additional Information/Prepared Reports

Personnel from a variety of agencies and private organizations involved in developing special events traffic plans were contacted by phone and asked if they would be willing to complete the survey and, if possible, provide supplemental documentation. After agreeing to participate, these contacts were provided with a copy of the survey questions by fax or e-mail, and a deadline was established to complete the survey, either by phone, by fax, by mail, or by e-mail.

3. Compile and Analyze Results

After receiving the completed surveys and any additional information, the results were compiled for comparison and analysis. Comparison involved identifying similarities among the various agencies and their plans, particularly among the problems and corresponding solutions specified by the agencies. Analysis involved evaluating the effectiveness of the various plans and solutions, and any changes made to increase effectiveness. This comparison and analysis allowed identification of trends and patterns both in problems and in solutions.

4. Develop Recommendations

After identifying trends and patterns in the analysis of results, a list of recommendations was made for use in the development of a new or revised special events exit traffic plan. These recommendations used the information gained from the efforts of the agencies surveyed, and they helped to identify possible priorities in facilitating traffic as well as potential problems and corresponding solutions that will determine whether those priorities are satisfied.

5. Perform a Case Study

The recommendations developed from the survey results were applied to the development of a plan to facilitate exiting traffic at special events at the Astrodome in Houston, Texas. A set of priorities was established based on the trends identified in analysis, some potential problems were identified pertaining to the specific characteristics of the events and the city, and solutions to those problems were proposed.

Definition of “Dump Time”

When describing the efficiency or effectiveness of an exiting traffic plan, the term “dump time” is often used. “Dump time” is also used frequently in this paper as a measure of effectiveness; however, the specific definition of this term varies depending on the city, agency, or event under consideration. A general definition of “dump time” could be considered to be: “the amount of time needed to empty a venue’s parking area to the point that the remaining vehicles are still in the parking area by the choice of the drivers.” Implied in this definition is that traffic on arterials and freeways used as exit routes is free-flowing, or operating above level of service F.

LITERATURE REVIEW

Contained within this section is a brief discussion of literature related to special events traffic and traffic management. This discussion is intended to provide a foundation for the information and recommendations provided in the following sections of the paper.

Introduction

Transportation, in general, involves the movement of persons, goods, and services from place to place. An ever-growing proportion of transportation takes place in urban areas, specifically on urban freeways. However, the flow of traffic on urban freeways can be adversely affected by incidents such as traffic accidents, maintenance operations, and temporary blockages due to large traffic volumes. Many studies document that incidents can have serious impacts on traffic, manifested in terms of congestion or delay. It is recognized that each minute of blockage during commuter periods on the freeway results in five minutes of motorist delay. An objective of each urban transportation agency is to respond to disruptive incidents within its respective jurisdiction and relieve congestion as quickly and safely as possible (1).

Incidents related to special events are somewhat unique in nature, in that they are not high-frequency recurrent incidents similar to peak-period congestion, which occurs daily. However, event-related incidents are still somewhat predictable, in contrast to random incidents such as traffic accidents or effects of adverse weather. In general, a significant portion of event-related congestion occurs on certain freeway segments at or near the event venue. In many cases, there are alternate routes for both event and non-event traffic, but often they are not fully utilized because drivers are either unaware of them or they have no knowledge of the severity of congestion in the venue area. Although the effects of many special events can be predicted from historical data by traffic planners and are expected by motorists who regularly attend these events, the congestion that develops is often unexpected by non-event motorists in the area (2).

Strategies and Solutions

Operational studies have shown that managing traffic after special events will result in extremely high payoffs in terms of reduced congestion and delay. Strategic plans to facilitate the movement of post-event traffic can be very beneficial both to event-related traffic and non-event traffic. The determination of specific event venue exit routes and the supply of relevant information to all motorists in the area can produce a variety of benefits. Some of these benefits are: advance decisions on route selection and time of travel; diversion of non-event traffic to alternate routes; improved merging of event traffic on area freeways; and, ultimately, a reduction in congestion.

Incident management requires coordinated and preplanned procedures to restore traffic to normal operation through the use of all available human and electronic/mechanical resources. In general, these procedures include: 1) detecting the incident; 2) identifying the incident; 3) identifying the response requirements; and 4) providing the appropriate aid to the motorists involved to minimize the effects on the transportation system

by clearing the incident area as quickly as possible. The benefit to event-related incident management is that, to a certain degree, the first three procedures can be completed in advance. Using this fact in developing an exit traffic plan allows the implementation of the plan to be focused on actually providing aid to clear the event area quickly (3).

Of fundamental importance in any traffic management plan is multi-agency communication. Response needs for most major freeway incidents extend beyond the capability of a single agency, and special events are no exception. Different agencies have different responsibilities and objectives when responding to event-related traffic incidents. These responsibilities have different priorities in the overall traffic plan; however, decisions and actions by any one agency must be compatible with those of the other agencies involved. Part of proper planning for post-event traffic is a means of establishing the chain of command, flow of relevant information to aid motorists, specific responsibilities of each agency, and resources that will be provided by each agency. As a result, it is necessary to establish multi-agency consensus for needs and priorities, establish interagency cooperation agreements, and develop interagency communication protocols. After the basic structure for interagency cooperation and coordination is established, the involved agencies can improve their preparedness for post-event traffic (1).

There are a variety of aspects that need to be considered when implementing technologies and solutions to facilitate post-event traffic. One aspect is traveler information, which is vital for the reasons stated earlier; that is, providing drivers with accurate information that their intended route may be blocked or severely congested can help eliminate a proportion of excess travel. There are several methods commonly in use for this purpose; some of them are: traveler advisory radio, specialized maps, temporary signing, and kiosks. Traveler advisory radio can be used to warn drivers within a localized area of short-term delays caused by preplanned activities such as special events. Drivers who receive these messages can make routing decisions before entering the affected area, thus avoiding post-event congestion altogether. Specialized maps can be used to inform event attendees of preferred exit routes and their designated directions of travel; these maps can be distributed before or during events to allow drivers to decide on their exit route before entering the post-event traffic stream. Variable message signs and temporary static signs can be placed to provide route- and location-specific messages regarding changes in traffic conditions. These signs can be used to indicate downstream congestion, lane closures, channelization, or suggested detour routes. Informational kiosks can be placed inside event venues to display updated area traffic conditions and information on preferred exit routes; this will further enable event attendees to make informed decisions about their travel away from the event venue.

Signal and traffic control systems are also important in post-event traffic. Because of the large volumes of traffic generated by special events, signal systems on adjacent intersections often cannot function adequately. As a result, changes must be made to expedite the flow of traffic. One solution is real-time signal system adjustment, which allows an operator to make changes in timings and phases based on the current level of demand. This ability can be used to provide more green time to the heaviest traffic volumes, while reducing green time for lesser movements, thus improving the efficiency of the signal. Another method of traffic control is physical channelization, which involves the use of devices such as barrels, cones, and barricades to physically block access to a particular street or lane. This method is often supplemented by the use of traffic police or other law enforcement to help direct the flow of traffic and prevent violation of control devices.

A third major aspect of post-event traffic is freeway and corridor control; it is necessary to make sure that all of the other strategies and solutions are working properly in order to maintain traffic flow. A popular method to accomplish this is the use of a traffic management center. Traffic management centers are vital requirements for integrating advanced technologies to improve conditions on urban freeways. These centers provide capabilities of monitoring traffic flows, providing information to motorists through variable message signs and advisory radio, and communicating with personnel from various agencies participating in the traffic

plan. These capabilities are all used to optimize the use of corridor capacity by altering the flow of non-event traffic to better accommodate the large volumes of event-related traffic (4).

Implementation

A number of the strategies and solutions discussed above either have been or are being implemented in various locations around the country. The remainder of this section contains examples of these strategies and solutions in selected cities.

Perhaps no annual event in the United States attracts as much attention, and as many people, as the Super Bowl. As part of preparations for Super Bowl XXXII at Qualcomm Stadium in January 1998, officials in San Diego, California, worked to implement the Mission Valley ATIS-ATMS (Advanced Traveler Information System-Advanced Traffic Management System) program. Specifically, the first phase of this program dealt with improvements in and around Qualcomm Stadium, and included elements for corridor control, traveler information, and a transit alternative. Closed-circuit television (CCTV) cameras were installed to be aimed at the streets outside the stadium, thus enabling surveillance of area traffic conditions. Variable message signs were installed to guide drivers into various lane configurations and parking lots. The new Mission Valley Trolley Line was built to encourage attendees to park elsewhere and ride to Qualcomm Stadium, where the largest station on the trolley line is located. Phase two of the plan is designed to integrate these special-events features with the California Department of Transportation area traffic management system. Although the official evaluation of the program's performance was unavailable, project officials were optimistic about the results (5).

Another Super Bowl-related project involved the use of a video detection system in Tempe, Arizona, outside Sun Devil Stadium, site of Super Bowl XXX in 1996. Officials there decided to use this system for managing the surge of event traffic in part because it would avoid adding to traffic problems by tearing up streets to install loop detectors. Traffic managers used the surveillance data to adjust signal timings at the primary intersection just outside the stadium, through which 40,000 people crossed daily during Super Bowl week (5).

The Rose Garden arena in Portland, Oregon is a relatively new facility that attracts thousands of basketball fans to Trail Blazers games and hosts other events such as musical concerts. However, the arena was built on a site in an already congested area. To help manage the congestion, city officials are utilizing a real-time traveler information system with significant use of variable message signs. There are at least two such signs directing drivers to parking lots or shuttle sites. It is the hope of city transportation officials that the new information system will be successful enough to encourage its use in other areas of the city.

As the use of these solutions becomes more common, more definitive results will become available concerning their effectiveness. However, officials in each of the cities mentioned above were encouraged by the possibilities of increased efficiency and optimized use of the transportation system in their areas (5).

SURVEY RESULTS

Introduction

This section contains the findings from the survey questionnaire, a copy of which is provided in the appendix. A total of 20 persons, representing 17 agencies in 11 cities, were contacted to participate in the survey. Of those contacted, 11 persons from eight cities agreed to participate, and 10 persons from seven cities actually completed and returned the survey. Table 1 provides a summary of the cities and regions represented in the survey, as well as the agencies that provided the information for the survey.

The remainder of this section contains summaries of the information obtained about each city, based on answers to the survey questions and any supplemental documentation provided by the agencies surveyed.

Table 1. Listing of Cities and Agencies Represented in the Survey

City/Region	Agency	Nature of Agency
Anaheim, CA	Anaheim Dept. of Traffic Engineering	Public
Kansas City, KS/MO	TranSystems Corporation	Private Consultant
Milwaukee, WI	WI DOT – MONITOR TransCore Milwaukee	Public Private Consultant
Orlando, FL	City of Orlando Public Works	Public
San Antonio, TX	VIA Metro Transit City of San Antonio Public Works	Public Public
Seattle, WA	WA DOT	Public
Washington, DC / Baltimore, MD	MD State Highway Administration MD State Police	Public Public

Anaheim

The city of Anaheim has a permanent population of about 300,000; however, the city also experiences an estimated 20-30 million visitors each year. Special events are frequent in Anaheim, and there are four main venues that will be discussed here:

- *Edison Field* – Home of the Major League Baseball (MLB) Anaheim Angels, with 81 regular-season home games per year and a capacity of 45,050. Edison Field is also the site of various Monster Truck events, soccer games, and large concerts.
- *Arrowhead Pond of Anaheim* – Home of the National Hockey League (NHL) Mighty Ducks of Anaheim, hosting about 40 games each season with a capacity of 17,174. The Pond also hosts other events including NBA exhibition games and boxing matches.
- *Anaheim Convention Center* – Hosts a wide variety of conferences and conventions each year; exact attendance figures were unspecified.
- *Disneyland* – World-famous theme park with millions of visitors annually. Disneyland also contains a resort area with hotels, dining, and entertainment.

The city of Anaheim has had some form of a traffic plan in place for well over a decade. In 1989, the city’s first Traffic Management Center was established; this center operates on a fixed schedule under normal conditions, but it also has an event-based schedule that allows officials to concentrate on conditions related to event traffic. Barring technical difficulties or construction problems, the Traffic Management Center is the central point of operation for all event traffic plans.

Anaheim’s priorities in establishing the current version of their event traffic plan were based on a Traffic Management Center-operated system. The city is divided into sections, each with its own individual traffic system; this sectional strategy allows the city to deal with each event separately. Each plan then becomes a modular plan; if a section is affected, a plan can be introduced to deal with problems in that localized area.

The City of Anaheim uses a wide variety of technologies and other solutions to address issues related to exiting special events traffic; some of them are listed below:

- Changeable message signs on arterials and (in conjunction with CalTrans) on freeways
- Dynamic traffic signal adjustments
- Highway advisory radio for arena and stadium events and the 91 Freeway corridor
- A fiber optic backbone for the transfer of information
- Video detection
- Traffic Police, employed primarily for directing and calming traffic and coordinating movement of pedestrians; law enforcement is generally confined to illegal parking
- Kiosk system, with real-time updates on freeway conditions and other information

City officials hold weekly meetings with event managers to evaluate current performance and investigate opportunities for improvement. Some specific measures of success or effectiveness include “dump time”, cost of resources used, and complaints about construction or traffic flow. Of those three measures, cost is considered to be the least important; Anaheim is willing to spend some extra money to improve the flow of traffic. Officials are more concerned with the amount of time it takes to restore normal traffic and with the public’s perception of their job performance. To this point, Anaheim has had great success with their traffic strategies, achieving better efficiency with more traffic.

Each of the venues listed above was designed to be in close proximity to Interstate highways. Thus they are all accessible to the large number of passenger cars and other vehicles that travel from the events. Estimated proportions of traffic leaving stadium and arena events are as follows: 90 percent passenger cars, 8-10 percent shuttle buses, and the remainder on tour buses. Traffic from the Convention Center is estimated to be a 70/30 split between passenger cars and shuttle buses, and Disneyland traffic is approximately a 50/50 split.

Transit options are available for all events at these venues, and they are highly encouraged. In addition to public transit, many hotels run shuttles to and from Disneyland, sporting events, and/or the Convention Center. There are also private shuttles and tour buses commonly available.

There are very large numbers of pedestrians at many of these venues, particularly at Disneyland. In fact, there are far more pedestrians at Disneyland than any other of these venues, but interaction between pedestrians and vehicles is much higher at sporting events due to the configuration of parking areas. Despite these high pedestrian volumes, Anaheim officials have not indicated significant problems with pedestrian accidents or injuries following special events (6).

Kansas City

The Kansas City metropolitan area straddles the Missouri River, which acts as the border between the states of Kansas and Missouri in the northern part of the metropolitan area. This unique geographical characteristic creates some interesting situations involving traffic and the solutions available to deal with it. There are a number of facilities on both sides of the river that generate significant special event traffic:

- *Arrowhead Stadium* – Home of the National Football League (NFL) Kansas City Chiefs with eight regular-season and two exhibition home games each year, Arrowhead is also the host of the Major League Soccer (MLS) Kansas City Wizards with 16 home games per year. The facility seats about 79,100 for football and about 20,500 for soccer, and it has a variety of seating configurations for large concerts.
- *Kauffman Stadium* – Home of the Major League Baseball (MLB) Kansas City Royals, Kauffman Stadium hosts 81 home games annually and seats approximately 42,000. Originally named Royals Stadium, Kauffman joins Arrowhead as the major components of the Harry S. Truman Sports Complex, which was opened in 1972. The Sports Complex is located in eastern Kansas City, Missouri.

- *Kemper Arena* – The Kansas City area’s major multipurpose arena, Kemper Arena is home to the Kansas City Blades hockey team, the World Team Tennis Kansas City Explorers, and the Kansas City Attack indoor soccer team. Kemper also hosts the Big XII Conference men’s basketball post-season tournament, other sporting exhibitions, and a number of concerts each year. The facility has a capacity of about 17,000, and is located just east of the Missouri River in Kansas City, Missouri.
- *Sandstone Amphitheatre* – Located in Bonner Springs, Kansas, Sandstone Amphitheatre hosts numerous concerts and musical events each year, including nearly every weekend during the summer months. Sandstone has an estimated capacity of 3,000.
- *Kansas International Speedway* – Currently in early stages of construction, the Speedway is located on the western edge of Kansas City, Kansas. The Speedway design consists of a 1.5 mile oval racetrack on 1,200 acres with an initial seating capacity of 75,000, which could be expanded in the future as demand necessitates. This facility is designed for NASCAR Winston Cup and Busch Grand Nationals auto races. The Speedway is expected to be open for the 2001 racing season and is anticipated to host four three-day events per year.

Each of the venues currently in operation has a plan in place to facilitate traffic leaving events, but much of the discussion in this paper will deal with the plan in development for the Kansas International Speedway (KIS).

It was important for speedway designers and transportation officials to thoroughly plan and prepare for the large volumes of traffic that would be generated for events at the facility, and a high level of communication among various city and county representatives, law enforcement personnel, and transportation officials was required to develop an adequate traffic plan. Five priorities were established in the formulation of this plan:

1. Maintain non-event traffic capacity on adjacent Interstates and local non-event traffic access,
2. Minimize delay time entering and exiting the event site,
3. Mitigate event traffic in neighborhood areas,
4. Maximize use of existing infrastructure, and
5. Provide positive traffic control, ITS applications, and information systems.

In order to properly address these priorities, officials are using three main strategies:

1. Computer analysis of service levels and traffic routing,
2. Proposed central traffic control center to monitor traffic queues, arrival rates, and direction and phasing of traffic flow alternatives, and
3. ITS applications to emphasize travel information and routing.

Each of these strategies has elements that are discussed in more detail in the following paragraphs.

The site of the Speedway is positioned to have access to Interstate 70 on the south and Interstate 435 on the east; these Interstate highways will be the primary routes for Speedway traffic. Direct access to and from the Speedway will be provided by five-lane arterial routes with reversible lanes. These arterial routes are served by three interchanges with I-70 and I-435. Arterial routes also serve traffic exiting the Speedway to the north and west. Ultimately, these routes also lead to I-70 and/or I-435; this strategy will allow traffic using the Interstate highways to be spread out over a larger area and lessen its effect on through and local traffic.

Law enforcement priorities involve meeting the demand of on-site parking availability and limiting the amount of exiting traffic that cuts through surrounding neighborhoods. For these priorities to be met, coordination between city police, the Kansas Highway Patrol, and KIS officials will be necessary to maintain the flow of traffic. In the proposed plan, city police will be responsible for managing traffic on local streets and Highway Patrol officers will deal with traffic on Interstate routes. This leaves KIS personnel with the responsibility for Speedway access spokes and their intersections with local arterials. To aid these personnel, a variety of

solutions have been proposed, but the most commonly utilized will be variable message signs used in coordination with traffic police and Highway Patrol cruisers. The signs will be used to provide advance information and direction to motorists, while enforcement officers will be on hand to manually direct traffic and enforce temporary lane closures and channelization on arterials and freeway ramps.

The Kansas City metropolitan area, in conjunction with the Kansas and Missouri Departments of Transportation, is also in the process of implementing an area-wide ITS plan, which includes the construction of a Traffic Management Operations Center. The Speedway management plan being developed will be included within this metropolitan initiative, and the center will be used in coordination with efforts by law enforcement personnel to encourage the most efficient use of the existing roadway infrastructure. Transit service will be available through three separate transit agencies in the Kansas City metropolitan area; this service will be highly promoted and served by a separate access facility.

Based on computer simulations, supplemented by observations at similar facilities, traffic proportions are expected to be approximately 85 percent passenger cars, 10 percent transit service, 3 percent tour bus, and 2 percent unspecified. This combination is expected to keep the external street system relatively free of pedestrians and allow officials to concentrate on vehicle traffic.

Officials have established three criteria to measure the success or effectiveness of their plan: 1) “dump time”, with a target maximum of three hours; 2) travel speed for through vehicles on Interstate routes, with a target minimum of 40 mph; and 3) number of enforcement personnel necessary to carry out the proposed plan, a target number for which was not specified. Based on computer simulations, the agencies believe their plan will be able to achieve these goals, but actual results will not be measured until 2001 (Z, 8).

Milwaukee

The Milwaukee metropolitan area is currently in a state of significant change in regard to special events facilities and venues; a key component of these changes is the construction of a new stadium, Miller Park, to house the MLB Milwaukee Brewers. At the same time, the Wisconsin Department of Transportation (WisDOT) is developing two major transportation improvements in the area: an ITS program, called MONITOR, for traffic management and traveler information (TM/TI) along the Interstate 94 Corridor through Milwaukee; and the resurfacing of US Highway 41, which intersects with the Corridor. Miller Park’s proposed location is adjacent to this corridor, as is County Stadium, where the Brewers currently play. As part of the Miller Park Infrastructure Development Project, WisDOT conducted a study to identify preliminary event management needs and develop conceptual TM/TI alternatives within the corridor and into the US-41 design. Their plan was to create a large, multi-stage project, which is integrated with the new stadium, to improve TM/TI along the entire corridor.

The I-94 Corridor serves as the main transportation link between Waukesha County and the Milwaukee Central Business District. The Corridor experiences several hours of congestion each day, and projections indicate that this congestion will increase. In addition to daily traffic, and excluding event locations that are open all year, there are more than 450 annual special event occurrences within the Corridor. In particular, there are a number of major special event sites located within or near the Corridor that account for the majority of the extra event congestion. Some of those sites are:

- *Milwaukee County Stadium* – Home of the MLB Milwaukee Brewers, it hosts approximately 80 home games per year from April to October.
- *Miller Park* – New home of the Milwaukee Brewers currently under construction, it will replace County Stadium and will hold about 43,000 fans. To be complete by Opening Day (April) 2000.
- *Bradley Center* – Home of the National Basketball Association (NBA) Milwaukee Bucks, International Hockey League Milwaukee Admirals, Indoor Soccer League Milwaukee Wave, and the Marquette University Golden Eagles men’s basketball team, it also hosts several major concert and entertainment

events. The Center averages between three and five major events per week, and has an estimated annual attendance above two million.

- *Midwest Express Center* – Milwaukee’s new convention center currently in Phase II of Construction. The National Governor’s Convention was hosted at the Midwest Express Center shortly after completion of Phase I in 1998. It is anticipated that large, high profile events will quadruple due to the new facilities, with as many as 40-50 major conventions each year.
- *Wisconsin State Fairgrounds* – Home of the Miller 200 and the 11-day Wisconsin State Fair. The fairgrounds staff has recently looked to generate additional revenue by increasing the number of auto races. Also, a plan has been approved to remodel the grounds and increase promotion as a year-round facility. The Pettit National Ice Arena is also located on the fairgrounds; the ice arena is the home of the national speed skating time trials. Estimated annual attendance at the Fairgrounds is more than 900,000.
- *Lakefront Festival Grounds* – Home of Summerfest, the world’s largest music festival. Over 11 days in late June and early July, the event typically draws more than one million people, not including several hundred thousand who flock to outlying areas to watch fireworks displays on the opening night of the event and on July 3rd. The Lakefront Festival Grounds also hosts several ethnic festivals such as Germanfest, Festa Italiano, Polishfest, Irishfest, Asian Moon Festival, Indian Summer, and African World Festival during summer months; these festivals each attract between 35,000 and 170,000 visitors over three to four days.

Some events and venues have had exit traffic plans in place for decades, while others have only begun to plan in the last few years. As a result, in order to accommodate long-term increases in traffic volumes, anticipated special event growth, and major freeway reconstruction in the area, a need was identified by both public and private sectors to improve and/or enhance special event-related traffic management and traveler information activities throughout the corridor. WisDOT officials began their efforts by determining what event management activities already existed. This was done through a series of phone interviews and interagency workshops with officials from special event organizations, city officials, and police departments in the area; based on the information received from these efforts, WisDOT began their strategies to deal with traffic at each venue.

Virtually all of the venues and events discussed here have some form of access to the I-94 freeway and involve significant numbers of passenger cars:

- *Milwaukee County Stadium* – Immediately adjacent to freeway with direct access. Predominantly passenger car traffic (90%) with a small portion of tour buses (10%).
- *Miller Park* – Immediately adjacent to freeway. Traffic anticipated to be the same as County Stadium, with perhaps a small increase in the use of tour buses.
- *Bradley Center* – Located downtown, two blocks away from existing freeway spur. Predominantly passenger car traffic.
- *Midwest Express Center* – Located downtown, three blocks from freeway. Local events generate passenger car traffic, while large conventions produce traffic from taxis and airport shuttles.
- *Wisconsin State Fairgrounds* – Adjacent to freeway. Large number of passenger cars, but also significant transit and tour bus activity.
- *Lakefront Festival Grounds* – A portion of the grounds is located under an elevated freeway; however, city streets are the primary routes used to access parking. Most visitors arrive by passenger car (about 72%), transit or shuttle bus (25%), or on foot.

Transit options are available for Summerfest and Wisconsin State Fair. Strategies that have been highly effective include providing shuttle service to remote park-and-ride lots and parking structures along major arterials at reduced rates. Very heavy pedestrian activity is not widespread, but an intersection in the vicinity of Summerfest routinely becomes saturated with pedestrians and vehicles. Also, a large number of pedestrians cross major arterials during State Fair because residents adjacent to the facility sell parking on their property at a reduced rate.

Since each venue has different specific needs, a separate traffic plan is developed for each one. The Miller Park plan is currently under development, and is more extensive than the plan for County Stadium, largely because all of the elements necessary for the plan can be designed and built into the new stadium. Specifically for Miller Park, several technologies and other solutions for facilitating exiting traffic have been or are in the process of being instituted. These are:

- Additional Freeway Variable Message Signs,
- Initial Deployment of Arterial Variable Message Signs in the Village of West Milwaukee,
- CCTV Video Sharing with Village of West Milwaukee Police and Fire Dispatch,
- Direct Video / Communications Link into Miller Park to the Milwaukee County Sheriff's office (Milwaukee County Sheriff is responsible for patrolling adjacent freeways and security on-site),
- On-ramp Gates to assist Milwaukee County Sheriff in restricting access at locations that are frequently closed,
- Traveler Advisory Radio,
- Dynamic Message Signs specifically for special event information, and
- Informational Kiosks inside Miller Park.

Despite the unique characteristics of each venue, there are some common issues in each venue's plan that can be addressed, which is why WisDOT is developing the MONITOR program. A key component of this program is the WisDOT MONITOR Freeway Traffic Operations Center, which is located in downtown Milwaukee. Typically engineers and/or operators from the TOC participate in traffic task force meetings to determine how MONITOR elements may be best utilized during special events. Representative actions typically exercised to assist in the management of exiting special event traffic include:

- Operate freeway and portable variable message signs,
- Operate traveler advisory radio,
- Freeze important CCTV images to the media and Milwaukee County Sheriff's Department, and
- Modify ramp meter timings.

Officials in the Milwaukee metropolitan area have made multi-agency communication and cooperation the highest of priorities in implementing their traffic plans. The initial I-94 Corridor Special Event Traffic Management & Traveler Information Study involved city officials and police department representatives from four cities, as well as officials from Milwaukee County, the Milwaukee County Transit System, the Milwaukee County Sheriff's Department, the State Fair, the Brewers, Summerfest, and WisDOT. This same high level of communication also involves detailed documentation of plans and strategies, and it has remained a priority in ongoing traffic operations and planned improvements (9-10.)

Orlando

The city of Orlando has two primary fixed venues that cause significant traffic congestion:

- *Orlando Arena* – Home of the NBA Orlando Magic, it also hosts other basketball games, Arena Football, hockey, and various shows and concerts. Events occur on an average of three per week.
- *Florida Citrus Bowl (FCB)* – Hosts the annual CompUSA Florida Citrus Bowl game every January 1st, and is the football home of the University of Central Florida. This stadium also hosts local high school football games, occasional NFL pre-season games, concerts, and Monster Truck and Motocross events. Approximately 20 events are held annually at the Florida Citrus Bowl.

Both of these facilities have had exit traffic plans in place since they opened, but the City of Orlando has modified these plans over time to continue to meet traffic demands. Combined, these two facilities host a wide variety of events; consequently, there are a number of priorities that city traffic officials have established in moving traffic after events. Some of these priorities include: one-way and street closure schemes; shuttle

bus operations; traffic assignment locations for police; parking flow schemes; disabled parking; charter bus parking; and limousine parking.

The Orlando Arena is located in the middle of downtown and is bordered by an Interstate freeway and two major state highways. The estimated traffic is 80 percent passenger cars, 10 percent transit, and 10 percent walk-up. The transit service for Arena events is a bus circulator that utilizes exclusive lanes. The FCB is located west of downtown, in a residential/commercial area, but is also bordered by two major state roads and an expressway. For the annual CompUSA Florida Citrus Bowl, traffic proportions follow a pattern of 50 percent passenger cars, 20 percent charter buses, 15 percent shuttle buses, and 15 percent walk-up traffic. Other events at the FCB are less predictable and modal splits can vary significantly. Both venues have numerous local, arterial, and collector streets to facilitate traffic flow.

Based on this knowledge of their facilities and events, the City of Orlando implemented a variety of technologies and other solutions to address post-event traffic problems. A key component of the plan for the Arena involves the use of fiber optic parking directional signs, which are used for both pre- and post-event traffic. For events at the FCB, variable message signs are used to alert motorists of congestion related to event traffic and to direct fans to shuttle park-and-ride locations.

Since the amount and modal split of traffic can vary widely, particularly for FCB events, the City of Orlando keeps a high priority on the ability to change their traffic plans “on the fly.” For example, local college football games often generate major traffic volumes on the west side of the stadium, while the fan base for a Monster Truck or Motocross event often originates south of the stadium. In these situations, it is of utmost importance to be able to adapt and not be over-committed to the plan originally designed for the event.

Orlando has a Traffic Management Center that works with event staff to adjust pre- and post-event signal timing for Arena events. However, there has been much less success in implementing a signal timing plan for FCB events due to heavy pedestrian/vehicle volumes and conflicts. Both venues experience a high degree of pedestrian/vehicle interaction, largely due to the location of parking facilities and the large number of vehicles that park in adjacent neighborhoods and on private property. Traffic officials have, on occasion, attempted to establish post-event “pedestrian corridors”, but they achieved little to no success. Policing of these corridors proved expensive and difficult, and it became a public relations problem as people were directed along specified routes and then often had to double-back to get to their destination. Vehicle traffic moves very slowly immediately after events, which usually allows ample time for pedestrians to make their way through parking lots and adjoining streets. Thus, the pedestrian corridor plan was discontinued.

As mentioned above, transit options are available for events at Orlando Arena by the use of a downtown bus circulator. It is a free shuttle service that encourages fans to park at remote sites and ride to and from the Arena. There are 11 shuttle stops in the downtown area, with the primary station located in a parking garage at the Arena. During selected events at the FCB, the City of Orlando and their local public transit service partner an agreement to provide round-trip shuttle service for \$3 per person. This service is not provided for all events, however, as ridership for certain events has historically been extremely low.

Due to the pedestrian interaction noted earlier, law enforcement after special events is generally confined to encouraging the continuous flow of traffic. Jaywalking is rarely enforced, and illegally parked vehicles are ticketed or towed only if they obstruct line of sight or create a hazard to pedestrians. The city must also address the “business as usual” aspects of local businesses in the area. Based on this principle, they do not implement one-way traffic plans on streets surrounding the Arena, primarily due to a large hotel that is adjacent to the arena. Attempting to keep local traffic flowing through the area is a challenge that the city must face after each event.

Orlando generally measures their success in “dump time”. The Orlando Arena has a capacity of approximately 16,000 and has a target of about 35-40 minutes. The FCB has a capacity of approximately

72,000 and has a target of about 75 minutes. The plans and strategies used by the City of Orlando generally meet these target times.

In the summer of 1994, Orlando was a host site for the 1994 Men's World Cup. Soccer games were held at the FCB on five different days in late June and early July. Many of the strategies used in the World Cup exiting traffic plan were adapted from normal exiting traffic plans used for FCB events. A 29-member team from the Orlando Department of Public Works was stationed at strategic sites throughout the area surrounding the event. Each was equipped with a radio and assigned to a specific aspect of the traffic plan, such as street closure or traffic signal operations. Key components of the World Cup post-event traffic plan were: extensive use of lane closures and directional lane schemes; dedicated lanes for shuttle buses and law enforcement; widespread use of signing for temporary detours and directions for local traffic; adjustment of signal timings; and an extensive park-and-ride shuttle bus system (*12, 13*).

San Antonio

San Antonio hosts a number of events each year, ranging from sporting events to seasonal festivals. Primary venues for these events are:

- *Alamodome* – A multipurpose stadium, it is the home of the NBA San Antonio Spurs with four pre-season and 41 regular-season games, plus playoffs. Most Spurs games draw approximately 20,000 per game, but attendance can reach as much as 32,000 for selected games. The Alamodome is also the site of the annual Alamo Bowl and hosts the Big XII Conference football championship every other year; with attendance at both events estimated at 65,000. Other annual events include about six major concerts and shows (attendance above 40,000) and 10-12 smaller shows (attendance above 20,000).
- *Downtown San Antonio* – A multi-block area in the heart of the city that includes the Riverwalk and is the site of several major festivals each year. Fiesta is a 10-day festival in April highlighted by: three major parades that each draw 250,000; “Night in Old San Antonio”, which is a four-night street party with 100,000 in nightly attendance; and Fiesta Oyster Bake, a two-day event that draws 50,000 each day. The Texas Folklife Festival is a four-day event in August at the Institute of Texan Culture; it brings in between 40,000 and 50,000 each day. The Holiday River Lighting immediately after Thanksgiving draws 50,000-100,000 attendees, and the New Years Celebration attracts 100,000-250,000 to a street party and fireworks.

San Antonio has had a traffic/transit operations plan for the Alamodome since it was opened in 1993; operating plans for other events have been developed and modified as needed. The vast majority of the discussion below will focus on the Alamodome plan.

City officials gathered the input of the community, business interests, political entities, and transportation professionals to develop a set of priorities for their traffic plans. Those priorities include:

- Provide for safe ingress and egress of event attendees,
- Control on-street parking in adjacent neighborhoods,
- Maintain non-event traffic and transit flow, and
- Accommodate downtown pedestrian movements.

In order to address these priorities, city officials implemented several solutions. They built the Robert Thompson Transit station adjacent to the Alamodome, where they can transport more than 20,000 attendees per hour from the Alamodome to parking shuttles and Park & Ride lots. They also implemented the TransGuide traffic management system. TransGuide is a regional traffic management/operations center. It is utilized on a daily basis, but is particularly helpful for events. This center coordinates activities such as ramp closures, adjustments for accidents and congestion, and the display of messages on variable message signs to describe parking availability and suggested exit routes. There is a TransGuide work station in the

Robert Thompson Transit Station, which allows traffic and transit operations professionals to access all of the TransGuide cameras and communications from the middle of an event.

Related to the community's priorities, law enforcement is generally limited to on-street parking in adjacent neighborhoods. City officials monitor complaints from residents in those neighborhoods to gauge their performance. Other performance measures include "dump time", with a target under one hour, and the percentage of attendees using transit. Based on results from previous events, the dump time target is almost always met. In addition, officials use on-site observations and assessments to evaluate performance in specific situations; records of post-event traffic are compared to conditions recorded in previous years to determine the effectiveness of changes made from year to year.

Modal split for Dome events largely depends on the size, type, and attendee demographics for the event. The Alamodome has only 3,000 parking spaces on site; a 48-foot wide pedestrian walkway connects the Dome with downtown parking. Events less than 20,000 generally do not require transit service; at 20,000 in attendance, transit usage is about 10 percent. As the size of the event grows, so does the transit percentage, up to about 50 percent for a 65,000-person event. Passenger car access to the area is plentiful, and is the usual mode of choice. There are dedicated direct entrance ramps from Thompson Station to Interstate 37 for Dome events. I-10, I-35, and I-37 form a loop around downtown, providing easy access to the entire area.

As mentioned above, available transit service varies with the event. San Antonio has five basic Special Event Park & Ride sites around the city. Only one may be utilized for small events, while all five may be necessary for very large events. Downtown parking shuttles are only used for very large events and the length and number of shuttle routes may be adjusted to better meet event needs.

The pedestrian walkway to downtown parking is fully grade-separated as it crosses over and under parts of I-37 in the downtown area; there are no traffic conflicts until the walkway empties at a downtown intersection, which is closely monitored by San Antonio police. This walkway focuses most pedestrian activity on one route, but there are still occasional problems with pedestrians jaywalking across expressway entrance ramps, which police address when necessary ([14](#), [15](#)).

Seattle

Seattle hosts many sports-related special events, and they take place at a variety of facilities. This is a selection of some of those facilities:

- *Kingdome* – Home of the NFL Seattle Seahawks for 10 games each season, Kingdome is a multi-purpose stadium that seats 66,400 for football. It was also the home of the NBA Seattle SuperSonics until 1995 and home of the MLB Seattle Mariners until July 1999.
- *Key Arena* – Current home of the SuperSonics for approximately 40 games per season, Key Arena opened in 1995 and seats 17,072.
- *Safeco Field* – Opened on July 15, 1999, it is the current home of the Mariners for 81 games per season. A retractable-roof baseball-only facility, it seats about 47,000.

Less-frequent events in the Seattle area include the Goodwill Games, an annual PGA golf tournament, and two NHRA drag-racing events per year.

The Seattle area has had a comprehensive special events traffic plan in place for about five years. In that plan, officials gave high priority to moving large volumes of people in the most efficient manner. This was done by emphasizing high-occupancy vehicles, buses, and preferred parking. Some other strategies used by Seattle officials to facilitate exiting traffic include: police control at intersections; variable message signs; fixed signs; highway advisory radio; and helicopter observation.

The information provided to variable message signs and highway advisory radio is coordinated by Seattle's Traffic Operations Center, which is also used to inform the public of traffic conditions in non-event situations.

All of these events in the Seattle area are located in relatively close proximity to area freeways, which are the primary exit routes for special events. The estimated modal split for these events is 40 percent transit, 30 percent passenger car, 10 percent on foot, and 20 percent other. Transit options are available for all events, and use of these options is encouraged to the public, as evidenced by the modal split. There is a high degree of pedestrian/vehicle interaction, but there was no indication of any significant problem with accidents.

Seattle officials use complaints from the public as a way to measure effectiveness of their post-event traffic plan; other measures are cost of resources used, and press reaction to implemented strategies (16).

Washington, DC / Baltimore, MD

The large metropolitan area surrounding our nation's capital is constantly busy with a wide variety of special events. The Maryland State Police (MSP) at the Forestville Barrack and the Maryland State Highway Administration (MSHA) focus on three primary venues in Washington at which they jointly, along with local police and public works departments, provide assistance in mitigating traffic congestion:

- *Jack Kent Cooke Stadium* – Home of the NFL Washington Redskins for 10 games per year, it is also the site of concerts and other sporting events such as World Cup soccer. Capacity is approximately 80,000. Predominant modes of travel are: passenger cars 92%, tour bus 5%, transit bus 3%.
- *Six Flags of America* – An amusement park in the Six Flags chain that draws about 30,000 attendees per day. Predominant modes of travel are: passenger cars 95%, tour bus 5%.
- *Andrews Air Force Base* – Hosts an Open House each year, which draws about 800,000 visitors over a three-day period. Passenger cars make up virtually all of the event traffic.

The involved police and highway agencies, working closely with facilities staff, have prepared Special Orders outlining their purpose and procedures for each of the three venues; these orders were prepared in 1997 for the stadium, in 1999 for Six Flags, and revised annually for Andrews AFB.

Their main priority is keeping traffic flowing into and out of the event venues and eliminating queues on adjacent Interstate highways. In addition, they work to reduce the traffic on major arterials and throughout local neighborhoods. Pursuant to these priorities, the flow of traffic is emphasized over enforcement. Illegal parking is targeted, particularly in residential neighborhoods, when it impedes efficient operation. Otherwise, their main concern is the direction of traffic.

Both the stadium and Six Flags are in close proximity to both an Interstate highway and major expressways. A primary interchange for the stadium was built on the Interstate for stadium use only. There are also two major arterial highways with lane control signal systems that lead to the Interstate from the stadium. Six Flags and Andrews AFB are located between the Interstate and a major highway and are both on a major commuting thoroughfare.

Transit options vary widely for these venues. For stadium traffic, free parking is allowed at surrounding Metro Center (subway) stations. Shuttle buses are also available to transport people to and from the stadium for a minimal fee; this service is widely publicized in both print and media coverage. Six Flags has no transit option other than Metro, which carries an insignificant number of riders to the park. Andrews AFB has sufficient parking for all event traffic and there is no transit service available.

Pedestrian conflicts can be very significant at these facilities. The stadium complex is not equipped to accommodate parking for all patrons; therefore, approximately 1,000-1,500 vehicles are parked about a mile away at an adjacent sports arena. This results in a large number of pedestrians (about 3,000) crossing the ramps of the Interstate interchange at the stadium. Six Flags experiences a high number of vehicles that drop

off children at the park and return later to pick them up. There is no designated place for parking or stopping for pickup, and this creates a high level of interaction between vehicles and children near the entrance to the park. MSP is working with the park to establish an area for this purpose. The ample parking at Andrews virtually eliminates any pedestrian-vehicle interaction outside of the parking area.

The various agencies utilize the MSHA Traffic Operations Center and a local Command Post located inside Jack Kent Cooke Stadium. Both sites use cameras to give real-time reports of post-event traffic conditions, which assists them in adjusting their strategies to maintain the flow of traffic. As traffic operations at each venue progressed in a positive manner, the agencies were able to reduce the level of manpower needed to adequately staff these venues, which caused a corresponding reduction in expenses. They still observe “dump time” at these venues, and they continue to monitor any complaints they receive.

Some specific technologies and solutions used by the agencies include: electronic traffic detection; cones and arrow boards; portable and stationary variable message signs; traveler advisory radio; broadcast audio messages to AM/FM radio stations; police officers at selected intersections; and aerial surveillance.

The MSHA is also involved in other events across the state, most notably in Baltimore. MSHA’s traffic management plans are created as new stadiums are built or events are planned. In addition to Washington-area events, MSHA is involved with traffic generated by the MLB Baltimore Orioles (Oriole Park at Camden Yards) and the NFL Baltimore Ravens (Ravens Stadium at Camden Yards). Less frequent events include major golf tournaments and concerts.

MSHA’s primary concerns are public safety and the orderly flow of traffic, which is directly related to efforts by their major partner, the MSP. Orderly and safe traffic flow requires timely and accurate traffic information supplied to motorists, stadium officials, and parking personnel. Multi-agency coordination is vital to the success of their strategy, and planning is key to anticipating potential problems.

The technologies used in the Baltimore area are similar to those used in Washington: CCTV; real-time signal timing plans; variable message signs; traveler advisory radio; and cooperation with commercial radio stations, either through traffic reporters or through the flagship station of a particular event in coordination with both the statewide Traffic Operations Center and local Traffic Operations Centers. Again, use of these centers to monitor and observe conditions has proven very successful in alleviating post-event traffic congestion. Credibility is of primary importance when relating information to the public, and the controlling agencies have had great success in establishing credibility and persuading motorists to use the information provided to them (*17-19*).

SUMMARY AND DISCUSSION OF SURVEY RESULTS

This section of the paper contains a summary of the information obtained from the survey questionnaire. Contained in the summary will be a discussion of the trends and patterns observed from the survey information. This discussion will be the basis for conclusions and recommendations outlined later in the paper.

Nature of Events and Venues

Information in this section is based on event and venue details revealed in the survey results. This is provided primarily for background information and does not lend itself to significant trends or patterns to be used in recommendations. Table 2 contains a list of the events described in the previous section and the number of cities in the survey that consider those events significant. The maximum possible number of cities for any event is seven, equal to the number of cities in the survey.

Table 2. Listing of Special Events and Their Frequencies in the Survey

Event	Number of Cities	Event/Venue	Number of Cities
Sporting Events	7	Concerts	6
Basketball	6	Conventions	2
Baseball	5	Amusement Parks	2
Football	5		
Soccer	5	Other	3
Hockey	4	Festival/Fair	2
Auto Racing	2	Air Force Base	1
Other Sports	5		

Table 2 indicates a heavy emphasis on sporting events traffic as being important to transportation officials. In fact, each city in the survey had more than one kind of sporting event that was considered significant. The wide variety of sporting events also reveals the large number of facilities that are in use or are being built to accommodate these events. Table 3 contains a listing of sports venues described in the survey, and their respective frequencies. As in Table 2, the maximum possible number of cities for any venue is seven.

Table 3. Listing of Sports Venues in the Survey

Venue	Number of Cities
Multi-Purpose Arena	5
Multi-Purpose Dome	2
Baseball Stadium	5
Football Stadium	3
Racetrack/Speedway	2

Based on Table 3, multi-purpose facilities are quite common; however, current trends toward single-occupant facilities are also evident in the survey results. In relation to exiting traffic, multipurpose facilities can simplify the preparations needed for an event traffic plan, because many events will occur in the same place and utilize the same infrastructure; personnel would be accustomed to the characteristics of that venue, and implementation of the plan could be more efficient. Conversely, single-event facilities have the advantage that post-event traffic plans for those facilities can be adapted to specific events and specially designed infrastructure to maximize efficiency.

Traffic Plan Characteristics

All of the cities surveyed have a plan in place to deal with traffic exiting facilities currently in use and are developing or adapting plans for post-event traffic from future facilities. The history of these plans largely depends on the facilities being considered, as most cities are implementing plans when new venues open. Indeed, for the most recent of these venues, a primary concern is the accommodation of traffic in the most efficient means possible. This factor influences the location of new venues, and it usually results in major infrastructure improvement projects included as part of the construction of the facility.

Most of the agencies participating in the survey indicated that their main priorities in establishing a post-event traffic plan were protecting the safety of the public and maintaining traffic flow in the vicinity of the event site. These two main priorities were related to other responses given: encouraging transit use, monitoring on-street parking in the vicinity, minimizing delay, and maintaining capacity and speed on area streets and freeways.

A number of respondents indicated that they employed significant input from the community, area neighborhoods, and business interests in establishing their priorities. This process also provided an added benefit in the form of increased credibility and positive public relations, which often made implementation of plans easier and more successful.

Application of ITS Technologies and Other Solutions

A wide variety of strategies were employed by the cities and agencies surveyed. Table 4 lists some of the technologies and solutions identified by survey participants as useful in facilitating exiting special event traffic. Similar to Tables 2 and 3, the highest possible number of cities for any solution is seven.

Table 4 indicates some significant patterns in the widespread use of certain strategies. All cities employ TMCs in their post-event traffic plans. Each city also uses VMSs for traveler information, on-site law enforcement officers, and some form of transit service. All but one city indicated they utilize on-site communications among the various agencies involved in traffic plans, and all but two noted the use of physical changes to the normal flow of traffic by channelization, reversible lanes, and/or ramp or lane closures. These results would seem to indicate a general acceptance of these strategies and their effectiveness. Indeed, on-site law enforcement and transit services are basically universal at special events and have been for quite some time. While TMCs and VMSs are newer strategies, they have also gained acceptance and have proven to be effective in many different situations and in many locations.

The remaining strategies listed in Table 4 are not necessarily ineffective; in fact, the cities that use them have indicated great success with them. However, most of these solutions are still relatively new for use in event traffic, and they are somewhat more difficult and/or costly to implement effectively. This has kept these strategies from becoming as widespread as the others. Still, three of these solutions – signal adjustment, advisory radio, and CCTV – have been implemented by more than half of the respondents; this would seem to indicate a growing acceptance for these strategies as well.

Law Enforcement

The majority of the cities surveyed reported that law enforcement after special events was largely limited to illegal parking and, in some instances, jaywalking. Enforcement personnel were more concerned with maintaining the flow of traffic and keeping it on designated exit routes in the proper directions. Parking enforcement was designed to remove any impediments to traffic along designated exit routes; jaywalking and pedestrian enforcement was designed to maintain traffic flow and increase safety.

Table 4. Listing of Technologies and Solutions Implemented by Survey Participants

Technology or Solution	Number of Cities
Monitoring by Traffic Management Center (TMC)	7
Variable Message Signs (VMS)	7
On-site Law Enforcement (Traffic Police/Sheriff)	7
Shuttle Bus/Park & Ride	7
On-site Multi-agency Communications	6
Channelization/Reversible Lanes/Closures	5
Dynamic/Real-time Traffic Signal Adjustments	4
Traveler Advisory Radio	4
Video Detection/CCTV	4
Kiosks	2
Helicopter/Aerial Surveillance	2

Measures of Effectiveness

Five of the seven cities in the survey indicated “dump time” as a means of evaluating the performance of their exiting traffic plans; five cities also reported that citizen complaints were a key factor. Four cities also considered cost of resources or manpower used in carrying out their plan. Measures used by single cities included traffic flow on surrounding routes, press reaction to the traffic plan, and percentage of attendees using transit. These results indicate a trend toward public involvement. As the time to restore normal traffic decreases, the public’s opinion of the traffic plan generally improves. Lower “dump time” also decreases the cost of resources and manpower, but cities that use cost as a measure of success generally indicated it was not the most important factor in gauging success. City officials were more than willing to spend a few extra dollars to improve the performance of the traffic plan and gain the confidence of the public.

Respondents also indicated that, based on their selected measures of effectiveness, their respective traffic plans enjoyed great success in moving large amounts of traffic efficiently. Some cities reported that they also compared results with records from similar previous events to determine relative successes and identify opportunities for improvement.

Traffic Management/Operations Center

As mentioned earlier, each city in the survey either has or is planning a Traffic Management/Operations Center (TMOC) as a key component of its special events traffic plan. Some cities in the survey use the TMOC primarily for events, and then monitor regular traffic patterns in non-event scenarios. Other cities utilize the event management capabilities of the TMOC as an added benefit of a facility that is required for everyday use. In either case, all TMOCs mentioned in this survey are primary elements in the successful implementation of their respective special events traffic plan. In fact, most of the cities in the survey use the TMOC as a central command post, where representatives from all involved entities and agencies can observe post-event traffic conditions and communicate with one another. If, for example, a particular intersection

becomes oversaturated with exiting traffic, officials can make real-time adjustments to signal timings and/or deploy traffic police to manually direct traffic through the intersection. The existence of a TMOC is an invaluable benefit to the efficient and successful implementation of event traffic strategies.

Exit Routes and Multi-Modal Concerns

Virtually all of the event venues considered in this survey are, or are designed to be, in close proximity to Interstate highways or other freeways. Some venues have dedicated interchanges, used only for venue events; other venues require short-distance travel on arterials or collectors before accessing the freeway. In either case, these configurations provide easy access for the large number of passenger cars that are anticipated for all events.

Passenger cars have been the traditional choice of event attendees, and probably will continue to be for the foreseeable future, based on modal split estimates in this survey. Outside of Seattle, the lowest reported percentage of attendees who use passenger cars for any event or venue in this survey is 50 percent. Seattle has placed great emphasis on the use of transit in their area, and has been able to reduce passenger car usage to an estimated 30 percent for some events. However, even if 30 percent of attendees use passenger cars, the result is a high number of vehicles that must all exit the same venue at approximately the same time. This is why the majority of respondents indicated that one of their priorities was moving event traffic to freeways as efficiently as possible. This involved minimizing event traffic in surrounding neighborhoods and significantly altering the normal flow of traffic on streets and roads in the adjacent area.

Despite the large volumes of passenger cars, transit use appears to be increasing in popularity where viable transit options exist. In addition to the high transit usage in Seattle, the cities of Anaheim, Orlando, and San Antonio also have events or venues with large numbers of attendees utilizing transit. Anaheim reported that use of shuttle buses approached 30 percent for Convention Center events and 50 percent for Disneyland traffic. Orlando indicated that as many as 35 percent of attendees of the annual Florida Citrus Bowl game utilized charter buses or shuttle buses. San Antonio officials said that up to half of attendees at the largest Alamodome events utilize transit options. Cities are encouraging a variety of transit options such as subways, light rail systems, and several variations of buses: regularly-scheduled public transit; event-based Park & Ride shuttles; downtown circulators; and privately-operated transit and tour buses. As transit use increases, cities and agencies can increase the efficiency of their traffic plans; more people leaving in fewer vehicles reduces the demand on the roadway system and allows event traffic to clear more quickly.

Pedestrian volumes at all of the events under consideration are very large, as one would expect. However, most respondents reported no serious problems with pedestrian accidents or other issues. In a few cases, a large number of pedestrians have to cross freeway ramps and/or arterials in order to access their parking area or transit station. These situations are generally dealt with by on-site enforcement personnel, but a prolonged problem may require a more permanent solution such as a grade-separated walkway. On the whole, event traffic moves slowly enough immediately after events that pedestrian/vehicle interaction is not a significant problem.

RECOMMENDATIONS

This section of the paper contains a list of recommendations for use in new or developing plans to facilitate traffic exiting from special events. These recommendations are based on the results of the survey questionnaire and discussion of those results contained in the previous section.

- *Utilize a Traffic Management/Operations Center as the central point of coordination*

A well-run traffic plan requires a great deal of coordination among event personnel and among all participating agencies. The most efficient way to facilitate this coordination is to have a single location where all involved agencies can have representatives who can communicate with each other. A TMOC can serve as a base of operations and can be furnished with the personnel and equipment necessary to carry out the traffic plan. TMOCs are designed to monitor traffic conditions throughout an area and be able to make immediate decisions concerning the re-routing of traffic and the assignment of emergency personnel. These are functions that are utilized extensively in post-event traffic plans, and the use of a TMOC to carry out these functions makes good use of resources.

- *Determine priorities that should be met in the exiting traffic plan*

The obvious priorities in any post-event traffic plan should be the most efficient movement of traffic away from the venue and the maintenance of public safety. However, it is necessary to go beyond that basic foundation and establish what elements are necessary to make those initial priorities possible. These additional elements could include the direction of traffic to freeways, the rapid removal of event traffic from adjacent neighborhoods, or the maximization of transit use. Definition of these detailed priorities will provide reachable goals and objectives that can be pursued.

- *Obtain and utilize feedback from the community and affected parties*

In order to properly establish the necessary priorities in the plan, it is necessary to obtain the opinions and concerns of the community. Ultimately, the success of any plan will depend on how well the traveling public follows that plan. Any plan that has public support will be more likely to succeed, because they will be inclined to understand and agree with the methods and goals of that plan. In particular, the concerns of affected parties should be taken into account. These parties can include officials from the event venue and event organizers, area businesses, residents of adjacent neighborhoods, and local media. The support of these groups will greatly increase the effectiveness of any plan that is implemented, and the use of their feedback will make the plan more relevant to the needs of the community.

- *Maintain a high level of communication and cooperation between agencies*

The success of any plan depends on the contributions of many different people from a number of different agencies. Elected officials, law enforcement personnel, transportation officials, and emergency services all have key roles to play in the implementation of a special event traffic plan. Each group has certain interests and aspects of the plan on which they must focus, and they require certain tools to do their jobs effectively. Therefore, it is necessary that all of these agencies understand each of their roles, understand what is necessary to fulfill those roles, and work together to ensure the best possible performance of each participant.

- *Determine what technologies and solutions are necessary to implement the plan and meet objectives*

After objectives have been established and each agency knows their responsibilities, it becomes necessary to define what solutions can be applied to meet the objectives effectively. A means of providing information to travelers is necessary, whether it be through the use of on-site traffic police manually directing traffic, or through the use of variable message signs, informational kiosks, or advisory radio to supply advance notice of changes to normal traffic patterns. If transit use is to be encouraged, there need to be viable and practical transit options in existence, with good access to parking areas and the event venue. The proper use of the correct applications is vital to accomplishing the objectives of the traffic plan.

- *Establish measures of success or effectiveness and use them to improve the plan*

In order to determine how well the plan works, there needs to be a means of measuring success or effectiveness. This can be accomplished by monitoring “dump time”, responding to public complaints, reducing the cost of resources used, or a number of other criteria. These criteria can be used as targets to strive for, or they can simply be used as a means of recording performance over time. After analyzing the results of implementing the plan, decisions can be made as to whether the plan was effective and whether improvements can be made.

- *Be willing and able to adapt the plan during implementation*

It is extremely unlikely that a plan is going to be perfect, especially on the first attempt. Therefore, it is important that the plan be flexible enough to make changes during implementation. If estimates incorrectly predict certain aspects of post-event traffic conditions, unexpected problems will arise. Contingencies should be available to compensate for those unexpected problems and deal with them as efficiently as possible. The ability to adapt during implementation will not only improve the plan's effectiveness, but it will also improve the public's image of the performance of agencies involved.

APPLICATION OF RECOMMENDATIONS: A CASE STUDY

The information contained in this section of the paper is intended to be an illustration of the development of a plan to facilitate traffic due to special events at a specific venue. It was formulated by the author to demonstrate the use of the procedures and recommendations contained in this paper. Specifically, it will rely heavily on the recommendations listed in the previous section. Each segment in the scenario described in this section corresponds to one of those recommendations.

Introduction

Houston, Texas, has the second-largest metropolitan area in the state, with a population of approximately three million occupying most of Harris County and parts of neighboring counties. Houston is the site of many special events of various natures. One venue for special events in Houston is the Astrodome, which is the home of the MLB Houston Astros for 81 regular-season games with a capacity of 54,313. The Astrodome also was once the home of the NFL Houston Oilers, and it is still the site of many other sporting events, concerts, conventions, and the annual Livestock Show and Rodeo (20). The Astrodome is located in south-central Houston, bordered by Interstate Loop 610 on the south, Old Spanish Trail (US Highway 90A) on the north, Kirby Drive on the west, and Fannin Street on the east. Six Flags AstroWorld amusement park is located across I-610. Figure 1 is a detail map illustrating the Astrodome area (21).

The information in the remainder of this section of the paper is based on the scenario created and developed by the author. With the exception of the advisory commission created specifically for this scenario, all of the agencies mentioned in this section actually exist; however, any actions by those entities described in this scenario are created by the author and do not necessarily reflect conditions in reality.

The scenario created by the author is based on the assumption that city, county, and event officials have decided that the plan to facilitate exiting traffic at Astrodome events needed to be updated to reflect infrastructure changes and current attendance and travel patterns. In order to update their plan, officials decided to completely reexamine their existing plan for ideas about possible improvements. They formed an advisory commission to study potential options and perform a wholesale reevaluation of strategies and priorities. Upon completion of their study, the commission would make recommendations to the city and county for their approval.

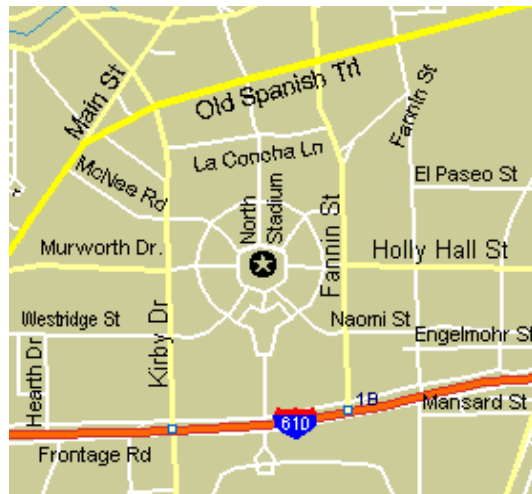


Figure 1. Astrodome Area Map

Traffic Management Center

Houston has a very active traffic management program, called TranStar. This program includes a traffic management center that is used to monitor traffic on area freeways, staff personnel from law enforcement and emergency services, and maintain lines of communications with agencies throughout Harris County.

The commission decided to utilize the TranStar center as the command center for their updated special events traffic plan. This would allow them to use existing facilities with trained personnel and appropriate equipment. Use of the TMC also centralized the operations of several agencies, streamlined inter-agency communications, and simplified preparations for implementation of the new traffic plan.

Priorities

In order to move event traffic away from the Astrodome quickly and safely, the commission decided to utilize Interstate 610 as the primary exit route. This strategy would involve channeling the majority of traffic to interchanges and frontage roads at Kirby and Fannin. Specifically, traffic would be divided such that all traffic exiting the Astrodome grounds by the southern two exits to Fannin Street would be directed to eastbound I-610. Similarly, traffic on the southern two exits onto Kirby Drive would be directed to westbound I-610. This is shown graphically in Figure 2.

To expedite the flow of traffic onto I-610, the eastbound ramps at Kirby would be temporarily closed, as would the westbound ramps at Fannin.

Much of the remaining traffic could be directed to the northern exits on Kirby or Fannin or to North Stadium Drive leading to US-90A where they would have two options; they could either turn southbound on US-90A and access I-610 away from the Astrodome or continue northbound and travel through central Houston to their destination.

A related priority that would be pursued would be the minimization of event traffic in area neighborhoods. If the majority of traffic can access the freeway and frontage roads, this would remove large amounts of traffic that would otherwise be creating congestion on adjacent streets.

A third priority was the use of public transit. Houston Metro transit has a number of regular bus routes that run on streets adjacent to the Astrodome, and a Park & Ride system could be easily established.



Figure 2. Exit Routes for I-610 Traffic

Public Feedback

After establishing some basic priorities, the commission decided to gather public input and feedback on their concerns and needs. Some groups that were specifically addressed include Astros season ticket holders, residents in adjacent neighborhoods, and owners of businesses along the I-610 corridor. In addition, officials from Six Flags AstroWorld theme park, located across I-610 from the Astrodome, were consulted to obtain their opinions and concerns. Comments from these groups were supplemented by feedback from advertisements made in the *Houston Chronicle*.

Analysis of public responses led the commission to include a few more considerations to their list of priorities. Nearby residents echoed the need to minimize neighborhood traffic. Season ticket holders wanted to be able to have preferred parking with easy access to exit routes, while local business owners were worried that the changes in traffic flows would adversely affect access to their establishments. Six Flags officials wanted to be able to coordinate activities with Astrodome officials to guard against both facilities releasing large traffic volumes at the same time.

General feedback indicated that many attendees found existing traffic control somewhat confusing, and they felt the time required to leave the event and make their way onto I-610 was too long. Furthermore, non-event traffic in the area often was caught in event-related congestion that could have been avoided had there been advance notification and opportunities to detour around the affected area. The commission decided to take all of these factors into account in their revised plan.

Interagency Communication

The commission was made up of members from the following entities: City of Houston, Harris County, Houston Police Department, Houston Fire Department, Harris County Sheriff’s Department, TranStar, Harris County-Houston Sports Authority, Houston Astros, Houston Livestock Show and Rodeo, Houston Metro Transit, Texas Department of Public Safety, and Texas Department of Transportation. Each of these agencies and organizations had a vested interest in the implementation and the success of the new traffic plan.

Commission members worked to establish responsibilities and obligations for each entity. These responsibilities were designed to be related to each entity’s specific interests and areas of expertise. As mentioned above, TranStar facilities would be used to have a central point of coordination. Police and sheriff’s officers would share enforcement and traffic duties on local streets, while DPS officers would be responsible for activity on I-610. The fire department would have EMT personnel on-site with a full firefighting crew stationed nearby. Metro officials would be responsible for transit service, including normal bus service and park-and-ride shuttles. TxDOT officials would work with the city and the county to design specific plans for re-routing and channelization of traffic. Event officials and the Sports Authority would be

responsible for helping to publicize the new plan and helping to pay for the cost of resources needed to implement the plan.

Commission members maintained an open dialogue among themselves, and worked to eliminate any jurisdictional or geographical obstacles. All of these responsibilities and obligations were included in a formal report outlining the entire Astrodome traffic plan, copies of which would be made available to each agency for their use. After creation of the plan was completed, commission members held regular meetings and special post-event meetings to discuss performance and problems.

Technologies and Solutions

In order to effectively route traffic to I-610, transportation officials felt it necessary to utilize a high degree of positive guidance and channelization. Traffic flow on both Kirby and Fannin adjacent to Astrodome grounds would be redirected to maximize capacity for exit traffic; this would be accomplished through the use of arrow boards, cones, barrels, and traffic police. Barrels and cones would be placed at each exit from the Astrodome grounds to guide traffic in the directions outlined in the exit traffic plan, so that traffic on southern exits would be directed to the south and traffic on northern exits would be directed northward. Arrow boards would be placed on Kirby and Fannin to guide traffic to freeway entrances on the frontage roads. An example of this guidance is shown in Figure 3, based on the section of Kirby Drive from Murworth Drive to I-610.

The high volume of exit traffic would result in a need for signal re-timings at the I-610 access road interchanges; personnel at TranStar facilities would be given the ability to monitor traffic levels and make adjustments to timings as necessary. Buses would be assigned to restricted-use lanes on the Astrodome grounds and given the use of temporary bus-only lanes on Kirby and Fannin.

Non-event traffic on area streets would be notified of pending increases in volume and changes in flow by portable variable message signs and temporary static signs, which would display informational messages and suggested detour routes. These signs would be installed on affected streets in advance so that messages could be displayed through the duration of the event as well as after the completion of the event. Traffic police would also be placed on patrols throughout the area to reinforce the messages, provide assistance, and enforce the law when needed. Suggested signing locations are shown in Figure 4.

Non-event traffic on I-610 would be reduced by one lane to allow for the large volumes of merging vehicles. This would be accomplished by channelization through the use of barrels and arrow boards, preceded by variable message signs. DPS officers would be strategically stationed throughout the corridor to observe traffic and enforce the law if necessary. An example of the positioning strategy for non-event traffic on eastbound I-610 is shown in Figure 5.

Law enforcement would primarily be limited to the removal of obstacles to traffic flow. Parking tickets would be issued for vehicles blocking exit routes, and citations would be issued to drivers who used bus lanes. Vehicle traffic on area streets would be periodically stopped by traffic police to allow pedestrians to cross and to create breaks in traffic entering I-610. Attendees who parked in areas south of the stadium would be encouraged to use an existing walkway over I-610 that connects to the grounds of Six Flags; this strategy would significantly reduce the number of pedestrians attempting to walk across freeway ramps and access road intersections.

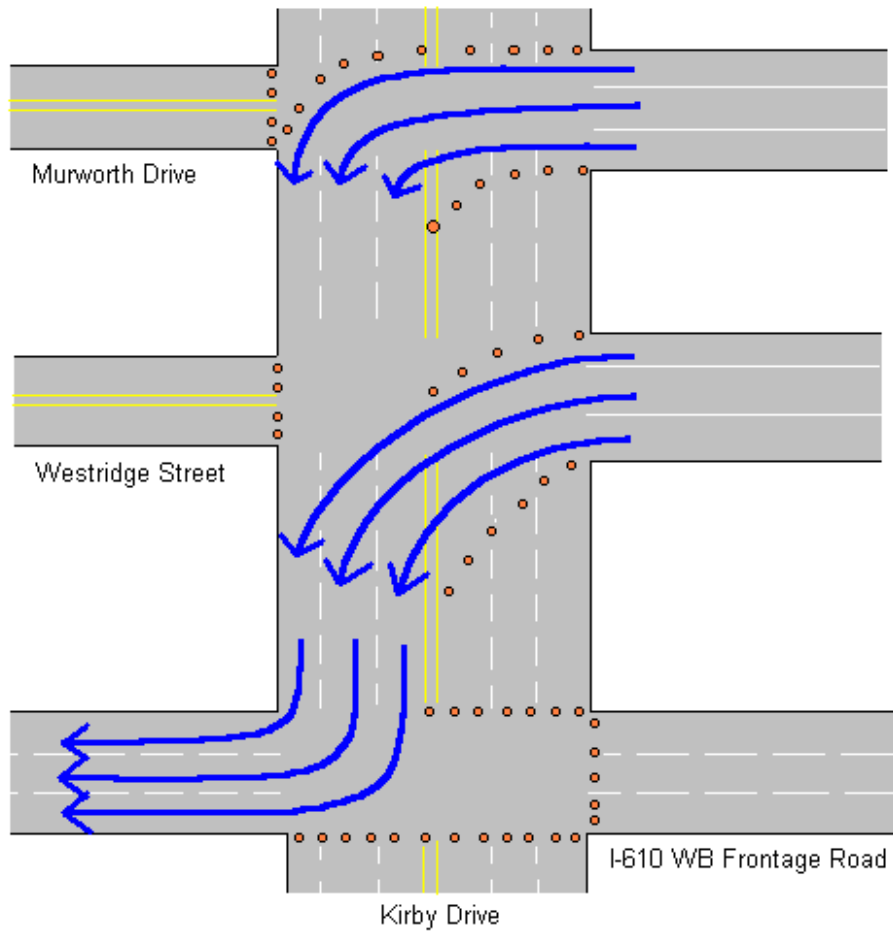


Figure 3. Guidance Strategy for Traffic Exiting on Kirby Drive

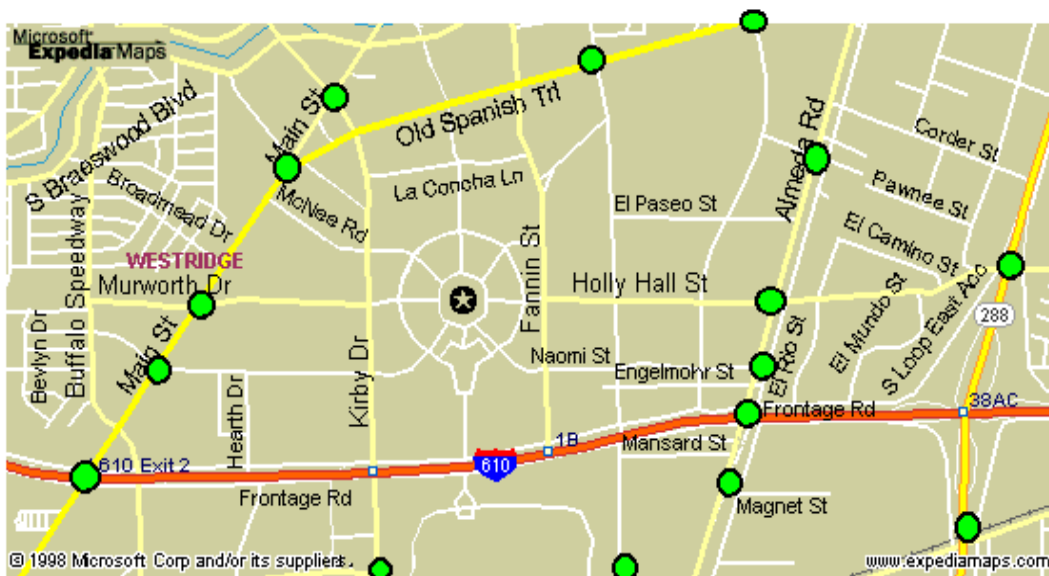


Figure 4. Suggested Deployment of Informational Signs for Local Traffic

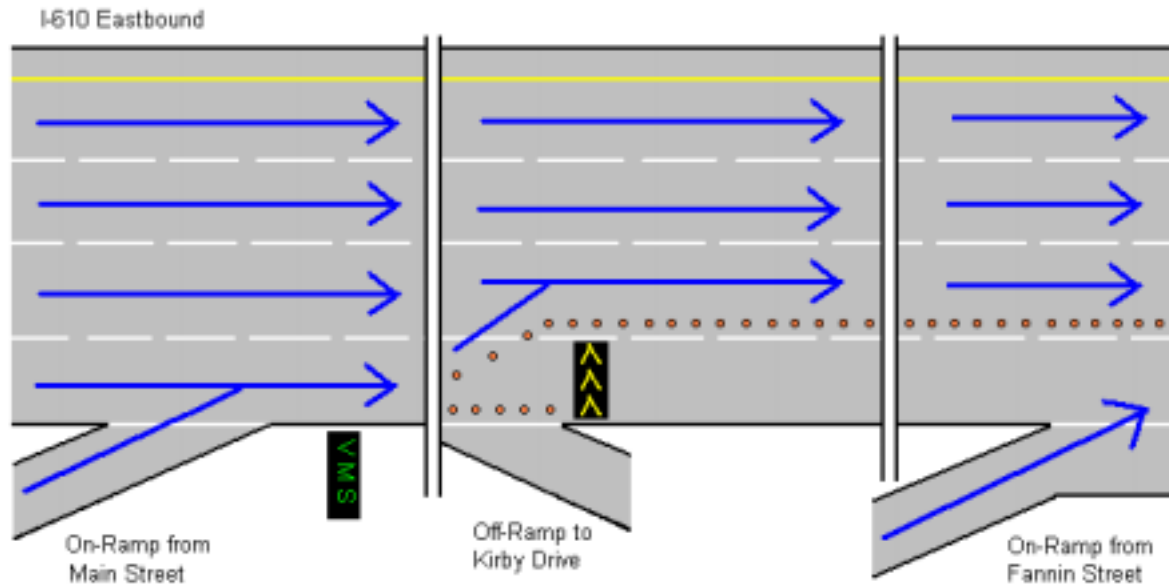


Figure 5. Positioning Strategy for Eastbound I-610 Non-Event Traffic

In order for the commission’s strategies to be effective, it would be necessary to provide adequate information to event attendees. This would be accomplished through several means. First, small detail maps outlining all exit routes and their direction of travel would be distributed to each Astros season ticket holder and included with group ticket sales. Additional copies would be made available for all other event attendees; these copies would be distributed two ways: the driver of each vehicle entering the Astrodome parking area would receive

a copy after paying the parking fee at the entrance gates; and supplemental copies would be available at the information office located inside the Astrodome. In addition, the maps would be reproduced in all media guides

and programs. Second, at the end of each game or event, images of the detail maps would be placed on the video board with accompanying announcements by the public address announcer. Third, kiosks would be installed at strategic locations throughout the Astrodome with information on exit routes and area traffic conditions. Use of these kiosks would be encouraged through public address announcements during and after each event. Finally, fixed and portable signs would be placed throughout the Astrodome parking area to guide travelers to the proper exits.

Measures of Effectiveness

Commission members agreed upon three primary measures of effectiveness for the new plan: “dump time”, public complaints, and cost of resources and manpower. The order in which these measures are listed is identical to their order of importance. The commission decided that “dump time” would be the single most important factor that attendees would consider. As the amount of time required to restore normal traffic flow decreased, the time that attendees spent waiting in the parking lot would also decrease. This would indicate that

implementation of the new traffic plan was successful in accomplishing a primary objective. A decrease in “dump time” would also lead to a decrease in the number of complaints received, according to the commission. People who spend less time waiting in the traffic queue will be more satisfied with the results of implementation. The other primary cause of complaints the commission anticipated was due to accidents or other factors that infringed on safety. However, it was the commission’s belief that a decrease in accidents

was related to more efficient traffic flow and a reduction in “dump time”. By attempting to eliminate the two main sources of complaints, the commission felt it could then focus on solutions to smaller problems that would help them fine-tune the plan.

Finally, cost of resources was considered as an important measure. This was partially due to the concerns of event personnel who wanted to keep their costs down. However, it was also related to the safety and morale of personnel involved. When traffic officers and management personnel can reduce the amount of time needed to complete their job, officers are exposed to fewer potential accidents and all personnel can go home earlier. Cost is also related to “dump time”; a decrease in “dump time” should translate to a decrease in cost, all other things remaining constant. Thus, the commission was primarily concerned with moving event traffic out of the area as quickly and safely as possible; the other measures would be by-products of that primary measure.

Adaptability

In order to know exactly how well the new plan was going to perform, it was necessary to implement it in the field under actual event conditions. Before doing that, however, commission members wanted to have some contingencies in place to deal with unforeseen problems. Key among those contingencies was ensuring that each officer and event personnel could be in constant communication with each other and with TranStar headquarters. The field officers could then make first-hand observations and relate them to other personnel for response. Incidents such as traffic accidents, stalled vehicles, medical emergencies, or fires could be reported instantly and the proper authorities could respond with necessary equipment and personnel. This would greatly reduce the time needed to deal with incidents and help restore traffic to normal.

Provisions were also made to allow traffic officers to manually direct traffic at intersections if necessary. If signal re-timings were inadequate or if an incident developed, signal operations could be coordinated between TranStar and police.

Traffic police also communicated conditions to each other, in the event that traffic patterns needed to be changed. For example, if too many vehicles were going south on Kirby to I-610, police at stadium exits could then direct more people north to US-90A to route them back to I-610 at a different interchange.

Implementation

Having identified priorities, participants, and solutions, the commission approved the use of the new Astrodome post-event traffic plan and recommended it to city and county officials. The recommendations were supported with thorough documentation of the goals and methodology the commission used in reaching their decision. The commission’s recommendations were then reviewed and approved by the City of Houston and by Harris County.

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- Mr. Roger Steinert, Washington Department of Transportation
- Mr. Todd Szymkowski, TransCore, Milwaukee, WI
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APPENDIX

Survey Questions

1. What is the nature of events at fixed venues that cause significant traffic congestion in your city or area? Specifically, what types of events (sports, concerts, fairs) and what frequency (annually, weekly, etc.)?
2. How long have you had a plan in place to expedite the flow of traffic leaving these events?
3. What elements were given priority in your plan to facilitate event traffic, and how did you determine those priorities?
4. What technologies or other solutions did you implement in order to address those priorities?
5. What issues (i.e., jaywalking, illegal parking, etc.) were emphasized in enforcement?
6. What did you use to measure success or effectiveness? (i.e., "dump time", cost of resources used, number of complaints received, etc.)
7. Based on those measures in Question 6, what were the results of implementing the plan in your area?
8. Do you have a Traffic Management/Operations Center in your city or area, or at the site? If so, how is it used in coordination with your special events traffic plan?

9. What are your primary exit routes for special events? Specifically, is the event venue in close proximity to Interstate Highways or other freeways?
10. What are the predominant modes of travel to the events and their approximate percentages? (i.e., passenger car, tour bus, transit bus, light rail, bicycle, on foot)
11. Are transit options available and/or adapted to special events? If so, is the use of these options emphasized and encouraged to the public?
12. Is there a high degree of pedestrian/vehicle interaction? (i.e., Do large numbers of pedestrians need to cross a major exit route in order to access a parking area or transit station?)
13. Do you have further documentation or a formal report outlining your event traffic plan? If so, are copies available to those who request them?



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**AN INVESTIGATION OF ADVANCED PARKING INFORMATION SYSTEMS
AT AIRPORTS**

by

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Advanced Surface Transportation Systems

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College Station, Texas

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SUMMARY

As a result of the recent increase in air traffic volume and the high degree of dependence on the automobile as the dominant mode of ground transportation to and from the airport, the access roads and parking lots at many of the nation's airports are experiencing additional demands. Additionally, when parking areas near capacity, circulation problems are compounded especially when travelers are unaware of the location of available spaces. Although all airports have parking guidance in the form of static signing as navigational aids, advanced parking information (API) systems attempt to alleviate some of the problems and hassles associated with searching for available parking spaces by using ITS technologies to first direct travelers to open lots or garages and then to specific bays.

The overall goal of this research was to develop an advanced parking information system using ITS technologies for communicating real-time parking information to airport users. In order to familiarize the author with issues related to airport parking and advanced parking information systems, a review of current literature and previous research was performed. To fill gaps in the literature reviewed regarding applications of API systems at airports, officials from airports with existing and planned systems were contacted and interviewed on the telephone. Additionally, data regarding user preference in parking information (i.e., information, location, and sources) was collected using a self-administered survey questionnaire.

Using the information gathered from the literature review, airport interviews, and survey results, guidelines for implementing an advanced parking information system to provide users with real-time parking availability or alternate parking suggestions at airports were developed. The guidelines include the following steps.

- Determine which parking facilities are to be included in the API system;
- Identify the parking guidance approach;
- Divide the global system into zones;
- Select the information dissemination strategy;
- Specify system characteristics;
- Determine the maximum capacity of the parking facilities;
- Develop and test system software;
- Deploy API System; and
- Evaluate API System.

To illustrate the use of the guidelines, they were implemented on the hypothetical expansion of the advanced parking information currently installed in Terminal C at Houston's George Bush Intercontinental Airport.

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INTRODUCTION

The implementation of the Intermodal Surface Transportation Efficiency Act in 1991 by the United States encouraged the development and use of technology to help manage urban transportation systems. This legislation has resulted in the advancement of intelligent transportation systems (ITS) technologies to provide enhanced mobility, safety, and traveler convenience. Advanced traveler information systems (ATIS) are a sub-component of ITS which offer static and dynamic pre-trip and en-route information (1). Examples of static information include transit schedules and fares, construction schedules, driving directions, and flight schedules and fares. Dynamic information includes, but is not limited to real-time traffic conditions, accidents, delays, parking availability, and route guidance.

In recent years the popularity of air travel throughout the United States has continued to rise. With this increase in air traffic volume and the high degree of dependence on the automobile as the dominant mode of ground transportation to and from airports, the access roads and parking lots at many of the nation's airports are experiencing additional demands (2). Parking area performance is a function of the time required to find a parking space. As parking areas near capacity, circulation problems are compounded when travelers are unaware of the location of available spaces. Repeated circling of the airport property while searching for an open space increases lost time and puts unnecessary strain on airport roads (3). Advanced parking information (API) systems (sometimes called parking guidance information (PGI) systems) use ITS technologies to help alleviate some of the problems and hassles associated with searching for available parking spaces by first directing travelers to open lots or garages and then to specific bays. These systems have the potential to benefit the overall operations of the parking and access facilities, improve the level of service for airport users, and possibly increase the airport's revenue (4).

Problem Statement

Air travelers are predominately concerned with getting to the airport on time by the quickest, most convenient, and most reliable means possible since they can usually ill-afford to miss their flights and are frequently on tight schedules. Time spent traveling by air can be divided into three categories including time in the air, time at the airport, and time on the ground going to and from an airport. Results from a 1994 study conducted by the Airport Council International-North America revealed that nearly 75 percent of airport operators surveyed indicated that passengers encounter more delay on access and circulation roads than they do on the airfield. These findings support the feeling, held by passengers and airport operators, that time spent on the ground is rapidly increasing (2). Since time spent searching for available parking is a large portion of the ground access time, utilization of an advanced parking information system to provide passengers with accessible and accurate parking availability and routing information at critical decision points could result in a reduction in travel time (5). However, in order to recommend guidelines for the application of advanced parking information systems at airports, research is needed to ascertain the specific type of information required by air travelers, especially considering real-time parking information. Moreover, the optimum location and preferred method of dissemination also need to be identified in order to assist travelers in making informed decisions prior to and during their trips.

Research Objectives

The overall goal of this research was to develop guidelines for the implementation of an advanced parking information system using ITS technologies to communicate real-time parking information to airport users. The specific objectives of this research included:

- Establish the information needs of motorists intending to park at an airport;
- Identify and assess potential ITS technologies to be used in disseminating real-time parking information;
- Investigate current advanced parking information systems;

- Develop guidelines for an improved advanced parking information system for airports; and
- Apply the guidelines to a case study at Houston's Gorge Bush Intercontinental Airport.

Scope

This research was limited to developing an improved method of disseminating parking information to airport users. It included a review of the process of collecting parking availability data to be used as traveler information, but did not address these issues in the guidelines formulated. In order to meet the objectives of the study, a survey of Texas Transportation Institute personnel who use airport parking facilities (i.e., short-term, long-term, and remote lots), an investigation of potential ITS technologies to be used in providing parking information, and a review of existing API systems were conducted.

Organization of Report

This report is organized into nine sections. The second section includes the methodology used to conduct this research. Background information including an overview of airport parking facilities, a discussion on advanced parking information systems, and a description of potential ITS technologies to be used in dissemination parking information are presented in the third section. A review of airports currently using advanced parking information systems is provided in Section 4. The results from the user information needs survey are presented in the fifth section. The sixth section includes an assessment of ITS technologies based on findings from the literature review and the results of the parking information needs survey. Guidelines for implementing advanced parking information systems at airports are found in Section 7. The application of the guidelines to Houston's George Bush Intercontinental Airport is in Section 8. Finally, conclusions formulated based on the results of this research are presented in the last section.

STUDY DESIGN

The procedures followed in carrying out this research to develop guidelines for the implementation of an improved advance parking information system to communicate real-time parking information to airport users consisted of four main tasks: literature review, data collection, data analysis, and application. These tasks are discussed in greater detail in the following sections.

Literature Review

A review of current literature was performed in order to examine previous research and present issues related to airport parking and advanced parking information systems. Specifically, previous studies of the impact of parking on airport landside operations, as well as the current methods by which air travelers receive parking information, and case studies of applications of advanced parking information systems were examined.

Data Collection

To fill gaps in the literature reviewed regarding applications of API systems at airports, officials from airports with existing and planned systems were contacted and interviewed on the telephone. The following questions were proposed to airport officials regarding the airport's API system.

- What is the capacity of your API system (how many spaces are covered by the API system)?
- What type of parking information do you give to passengers (no. spaces available, lot status, guidance to alternative lots)?
- How is parking availability data collected?
- How do you disseminate parking information to passengers?

Additionally, data regarding user preference in parking information (i.e., information, location, and sources) were collected using a survey questionnaire. The survey was distributed to random employees at the Texas Transportation Institute in College Station, Texas. A copy of the survey is provided as Appendix A to this report.

Data Analysis and Application

Using the information gathered from the literature review, airport interviews, and survey results, guidelines for implementing an advanced parking information system to provide users with real-time parking availability information or alternate parking suggestions at airports were developed. The guidelines were formulated using two methods. Existing strategies used by city-wide systems were adopted, and new strategies to address air traveler information needs and airport parking characteristics were developed. An enhanced parking guidance system for Houston's George Bush Intercontinental Airport was designed using the guidelines.

BACKGROUND

Airport Parking Facilities

When traveling by air, passengers are often on strict schedules and therefore generally rely on the automobile to get them to and from the airport as quickly, conveniently, and reliably as possible. This dependence on the private auto dictates that the airport provide a sufficient supply and proper allocation of parking spaces in order to ensure convenient access to the airport (2). This section of the paper includes a discussion of the types of parking available, how parking affects landside access performance, and applications of intelligent transportation systems technologies at airports as background to illustrate the potential for integrating an API system.

Types of Airport Parking

Airport parking consists of separate facilities for employees, rental cars, and passengers and visitors, with the latter broken up into short-term (i.e., hourly parking), long-term (i.e., daily parking), and remote lots (i.e., economy or park and ride). Short-term spaces are those located most conveniently to the terminal building and are available for a premium rate. Long-term parking is also typically located near the main terminal building, but is less convenient than short-term lots. As a trade-off, long-term parkers are usually given a discounted rate compared to short-term parkers. Remote parking areas are usually far removed from the airport terminal complex and are generally served by courtesy vehicles to transport passengers to and from their vehicles. Again, passengers are compensated for the remote location by receiving the most economical rate (6). Figure 1 illustrates the three parking area locations relative to Terminals A and C at Raleigh-Durham International Airport (7).

Parking's Contribution to Landside Access Performance

The overall goal when designing the access portion of an airport is the safe and efficient movement of passengers. The design and operation of parking areas significantly affect the performance of all airport access components. These elements, known as landside facilities include the parking areas, access roadways, and terminal curbside. Parking area performance is predominately determined as a function of the time required to find a space. Additionally, the time spent traveling (walking or riding) between a vehicle and the terminal and the conditions in which the trip takes place influence the level of service provided to passengers who park at an airport (2, 3).

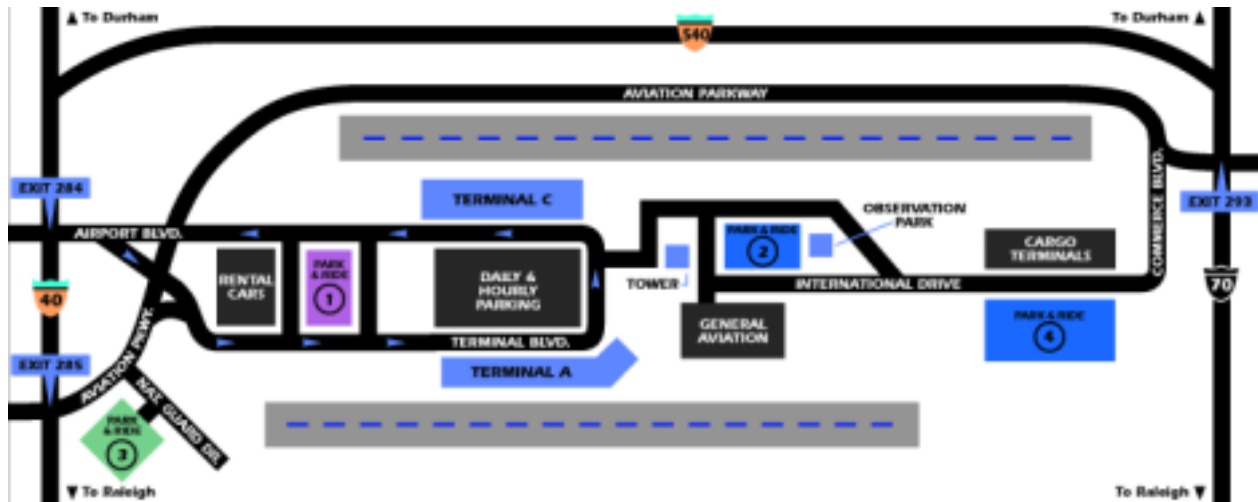


Figure 1. Parking Area Location at Raleigh-Durham International Airport

High turnover rates in short-term lots caused by high hourly rates imposed to discourage long-term parking, and parking areas operating at near capacity affect the performance of the roadways leading to and circulating through the airport. As a result, to ease the strain on airport roads caused by circulating vehicles, the number of required spaces calculated in the design phase of the parking lot is often greater than the expected demand. Overall, to avoid congestion on access roads and terminal curbsides, public parking that is conveniently located and provides sufficient capacity or immediate directions to available spaces is essential (2, 3).

Opportunities for Integrating ITS to Manage Parking Facilities

There are several ways ITS technologies can be utilized by airport authorities as a means of effectively managing their parking lots. These methods include the use of automatic vehicle identification (AVI) and automatic vehicle location (AVL) for traveler information systems and traffic management. By installing detectors in the entrances and exits or in each individual space of a parking lot, and connecting them to a central detector unit, the use of AVI and AVL concepts to gather information on space availability and vehicle parking duration is feasible. In the case of parking availability, the information is then distributed to incoming passengers via variable message signs, highway advisory radio, or telephone information systems so they can locate an open space as quickly as possible. Parking duration information can be used to calculate appropriate fees, which can be automatically debited if the vehicle operator has an existing account with the airport. In addition to parking guidance and automatic fee calculation and collection, ITS technologies can be effective in detecting illegally parked vehicles, increasing airport parking lot security, and reducing traffic flow inside the parking lot during congested periods (4). Table 1 includes a partial list of airports throughout the United States that currently or plan to use ITS to manage parking and ground transportation operations.

Overview of Advanced Parking Information (API) Systems

The first advanced parking information system was installed in Aachen, Germany in the early 1970s making parking guidance one of the oldest forms of traveler information. Advanced parking information systems use parking availability data to provide motorists with directions to open lots and vacant spaces in order to more efficiently operate a parking lot and reduce search times. There are several approaches and strategies to parking guidance and information dissemination that incorporate both static and dynamic message signs

Table 1. Examples of ITS Projects at U. S. Airports in 1993 (4)

Airport	ITS Initiative	Project Objectives	Status
Denver International	AVI system	Revenue collection, congestion control & ground transportation management.	Operational
John F. Kennedy	AVI system	Ground transportation management.	Operational
Los Angeles International	AVI system	Tracks commercial vehicles in and out of the airport, billing purposes, and to bill certain groups (courtesy vehicles) using accurate circuit counts.	Fully operational since 1990
Orlando	Commercial billing system	Fee collection.	Operational
Pittsburgh	AVI system	Collects commercial roadway fees and provides shuttle buses access to both the public and employee lots.	Operational
Washington-Dulles	HAR system	The system has 3 transmitters on the access road to the airport to provide parking information.	Operational since 1983
Washington National	Traffic information system	Provides information on parking availability and road construction in the airport.	Operational since 1982

to display lot status or the number of free spaces for individual lots or a city-wide system such that drivers can make effective decisions when choosing lot location, in addition to being guided efficiently within the facility. With studies showing that up to 33 percent of all drivers circulating within a city center are looking for parking, API systems have the potential to be an integral part of traffic management in and around the parking facility, especially under congested conditions (8-11). A discussion on the approaches used in parking information systems, the strategies used in disseminating information, how an API system functions, the benefits to implementing a system, and motorists' response to receiving parking guidance is included in the following sections.

Approaches to Parking Information Systems

The operation of parking information systems follow the same principles regardless of the overall guidance objective of the system. Whether guidance is provided on an individual lot or area-wide basis, the system will take on one of three approaches. These approaches are total space, zone-specific, and space-specific guidance.

Total Space Guidance. Total space parking guidance systems are currently used by airports, universities, and medical facilities among others to provide parking information to drivers on a single lot. In a total space guidance system, the number of vehicles entering and exiting a parking facility are counted and the current number of spaces available or lot status for that facility only are continuously displayed via a variable message sign just outside the lot entrance. This system does not provide alternative parking suggestions, as its purpose is to let patrons know the lot's status prior to them searching for an available space. Because of the limited guidance afforded by the system, it is the least expensive to implement (12).

Zone-Specific Guidance. Zone-specific guidance systems function similarly to the total space guidance system as they also detect all vehicles entering and exiting the parking area. However, in this system, the parking lot or garage is sub-divided into zones (e.g., levels of a garage or quadrants of large surface lots) and

vehicle movements are also detected for each section. As a result, real-time information is available on a zonal basis in addition to the total facility. This allows the system to be more specific in its guidance as drivers can be directed to bypass fully-occupied zones, thereby reducing search times. Zone-specific guidance is especially beneficial in multiple story parking lots with helicon ramps such as downtown and airport parking garages. In this design, drivers can drive upwards through the facility until they reach the first section with available spaces as indicated by the API system without traversing parking aisles. Additionally, large surface lots can also use this system when divided spatially (12).

Space-Specific Guidance. For a space-specific guidance system, detection equipment is installed in each individual parking bay within the parking area. Therefore, upon entering the parking area, drivers can be directed to an open bay based on the space occupancy information. Generally, the patron is directed via signs and/or traffic lights. Because detectors have to be placed in each individual space, this system can be extremely costly to implement and maintain (12).

Strategies for Information Dissemination

Advanced parking information systems employ a variety of different approaches when disseminating parking information to drivers. Two main strategies are descriptive and prescriptive approaches.

Descriptive Approach. A descriptive approach to disseminating parking information emphasizes increasing the parking choices available to the driver. Specifically, these systems attempt to communicate as much information as possible about the status of the parking system. This information would include a list of all the parking lots in the system along with directions to each lot. Additionally, the status of each lot would be given. As a result, the decision-making responsibilities are placed with the individual driver (13).

Prescriptive Approach. The prescriptive approach removes all decision-making responsibility from the driver and places it solely on the guidance system. Throughout the system, drivers are only relayed the information deemed necessary to proceed on to the next stage, even if information is withheld (13). For instance, if a parking area is full, only parking information for lots with similar or cheaper fares would be given as opposed to information on all lots in the system.

How the API System Works

Advanced parking information systems generally consist of four basic components including:

- the vehicle detectors;
- a parking control center;
- information displays; and
- a telecommunications network (10, 12).

Figure 2 shows a diagram illustrating the elements of a parking guidance system.

Vehicle Detection. The advanced parking information system must have a means of collecting parking space availability data to serve as input for the guidance system. The method of counting entering and exiting vehicles has a significant influence on the success of the system. If the data are inaccurate, calculation of available spaces by subtracting the number of vehicles entering and adding the number of vehicles exiting to the total spaces available will be erroneous. As a result, drivers will lose confidence in the information and the whole system will suffer (10, 12, 14).

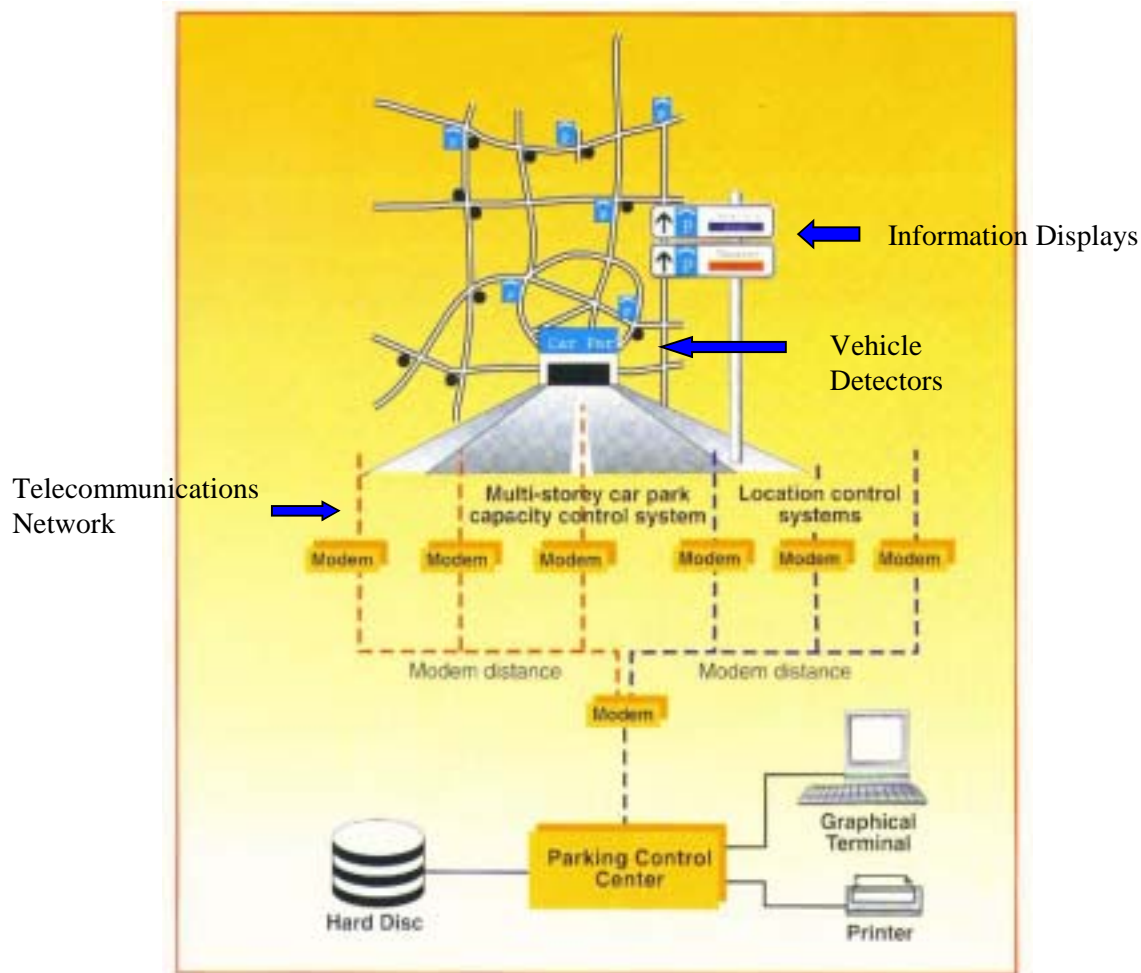


Figure 2. Schematic of an Advanced Parking Information System (10)

Methods of collecting traffic in-flow and out-flow counts include a wide range of technologies from barrier contacts, which count vehicles as entry/exit gates are opened, to inductive loops, ultrasonic, infra-red, microwave, laser, piezo, and machine vision sensor technologies that detect vehicles as they pass over or through sensors (10, 12). A summary and comparison of some of the main technologies according to Kevin Gavin of Appian Technologies is in Table 2.

Parking Control Center. The main function of the control center is to receive and edit parking availability messages generated by data collected from parking facilities, and then transmit them to individual variable message signs or other means of disseminating information for use by travelers. The hardware and software required to accomplish these tasks include a central controller with system software, a computer monitor, and a printer. These elements are available through various companies and are typically tailored to meet the specific needs of a particular system. Generally, the software automatically generates messages for information distribution based on the current lot status. However, using a color computer monitor and a graphical user interface, the system can be manually overridden for special events or unusual circumstances. Additionally, potentially problematic and non-transmitted parking availability information messages are also displayed on the monitor for manual intervention (10).

Table 2. Comparison of Vehicle Detection Technologies (12)

Performance Criteria	Method of Vehicle Detection			
	Inductive Loop	Ultrasonic	Infra-red	Machine Vision
Accuracy	2	6	6	6
Cost	5	2	4	2
Ease of Installation	2	1	5	3
Reliability	2	4	5	4
Lifespan	3	5	5	4
Effectiveness of Guidance Solution	2	6	5	6
INDEX	16	24	30	25

1 - Very Poor, 2 - Poor, 3 - Adequate, 4 - Good, 5 - Very Good, and 6 - Excellent

Information Displays. Use of effective information displays is critical to the success of the advanced parking information system as drivers need to feel comfortable accepting the information. Most importantly, motorists need information regarding the availability of parking. A combination of static and dynamic signs which provide drivers with parking availability information and directions to parking areas has proven effective. However, several other technologies have also been identified as means of providing parking information. These include highway advisory radio, the Internet, telephones, commercial television, and in-vehicle navigation. Additionally, distributing information on the number of spaces that the driver can expect to find when they reach the parking lot rather than the current number of spaces available is a recommended practice so that patrons are never faced with finding no available spaces when the signs indicated that at least one was free (10, 14).

Telecommunications Network. The telecommunications network is used to link the system together allowing the transmission of information between the parking facility, the control center, and the information displays by coding data into bit patterns. Typically, exchange of information takes place via one of two types of communications networks. The first option, dedicated networks consisting of specially-laid cables and infrastructure, is the more expensive alternative. Existing public networks like city telephone or signaling equipment control cables can also be used; however, limits on the number data channels available or on the quality of the transmitted signal sometimes dictate the use of a dedicated system (13, 15).

Benefits of API Systems

While parking information systems cannot create parking spaces, they have the potential to positively impact individual and city-wide parking areas, providing benefits to operators, users, and the surface transportation system. First, use of parking guidance can increase the efficiency or utilization of the parking facility as the distribution of accurate availability information results in empty spaces being filled faster, and thus higher occupancy rates. This increased utilization and higher occupancy rates, as well as quicker turn around times, directly translate into increased revenue for the parking operator. Additionally, zone and space-specific parking information systems provide parking operators with detailed management information such as occupancy, usage patterns, and throughput, which can be used in designing effective payment structures and

in checking the fraud detection process. Finally, operators can cut costs since manpower requirements are reduced in parking areas with an API system (8, 12).

Parking patrons benefit from a parking information system, since guiding them directly to an open facility reduces search time, queues, delay at the entrance, and ultimately driver frustration. When drivers are not forced to circle or wait for a parking space, they are more satisfied with the service and are likely to be repeat customers (8, 12, 16).

Installation of an advanced parking information system benefits the surrounding area by improving traffic flow and reducing congestion in and near the parking area. These enhanced conditions along with shorter search times contribute to a reduction in fuel emissions as car engines are running for less time (8, 12).

User Response to API Systems

The effectiveness and performance of the advanced parking information system as a traffic management tool is dependent on voluntary compliance by motorists. If a significant number of drivers do not follow the suggested guidance, the system will fail to serve its intended purpose. This premise is different from other forms of traffic control where drivers are required to conform (11, 13). Recently, several surveys have been carried out to discern the nature of drivers' awareness and use of advanced parking information systems as well as the system's impact on parking search behavior. A discussion of the results from three of these investigations is in the following sections.

Driver Awareness and Use of API. The first study, by Polak, et al., was conducted in Nottingham, England. After two years of using local radio stations to broadcast real-time parking information during Christmas time, drivers parking in public lots were surveyed to determine their awareness and use of the parking information service. Through the investigation, it was found that of the 1548 respondents, approximately two-thirds of drivers were aware of the system, while 25 percent of the respondents who knew of the system, had not used it (5). The second investigation was performed in Kingston-upon-Thames, an important suburban shopping center near London. Results from a survey of 180 shoppers who had parked at public off-street parking lots showed that there was a high degree of awareness (only 4 percent were unaware) of the system, which monitors occupancy levels at eight parking lots. However, of those that were aware of the system, almost half had never used it. Of the remaining respondents who used the system, 30 percent had used the signs recently, and 19 percent of them had used the system on the interview day (11). The final study was conducted in Frankfurt, Germany. Before and after surveys were completed by downtown shoppers who used on and off-street parking on Tuesdays and Saturdays in order to determine drivers' exposure to and use of the system. After three months of operation, 80 percent of the 3,506 participants (3,025 off-street, 481 on-street) were aware of the parking information system. The results also indicated that about 50 percent of off-street and 25-percent of on-street parkers have used the parking information at least once (17).

API's Impact on Search Behavior. Advanced parking information systems have the potential to establish or modify the method in which drivers search for desired parking locations. A survey of drivers parking on Saturdays in Frankfurt's shopping district revealed that only a couple of drivers completely depend on the parking guidance information at first. Rather, they use it primarily as a back up plan to find an open parking space if their first choice is not available. The results also showed that motorists are skeptical of giving complete control to the system since the number of drivers indicating they use the system as a fallback plan is about the same as those who simply parked illegally. Overall, very few respondents actually rely on the system for guidance. Most users only check or update previous decisions using the system (17).

Potential ITS Technologies for Disseminating Advanced Parking Information

Intelligent transportation systems have the potential to greatly enhance the operation of the surface transportation system through dissemination of accurate, real-time information. When informed mode, route, and time of travel decisions are made, the entire system benefits through improved safety, mobility, and traveler convenience. Several technologies, which are currently used in distributing traveler information to commuters, have been identified as possible mediums for disseminating parking availability and guidance information to air travelers. These technologies are included in the following list:

- Variable message signs;
- Static signs;
- Highway advisory radio;
- Internet service;
- Telephone information system;
- In-vehicle navigation systems; and
- Commercial television broadcasts.

Variable Message Signs (VMS)

Variable message signs are increasingly used as traffic control devices on freeways and urban roads to provide information such as alerting motorists of road closures, changes in traffic conditions, and lane closures, along with other traveler information. Although they are used to display information on daily occurrences and scheduled events, their primary function is to alert motorists to unpredicted, unscheduled events in an effort to help reduce speed, avoid congestion and accidents, choose alternate routes, and lessen frustration. Messages displayed on VMS are activated based on the existing road conditions and can be controlled on-site or remotely. There are numerous preprogrammed messages to choose from or operators can tailor them to meet specific needs. VMS are among the most effective ways to disseminate traveler information because they provide motorists traffic information about the very roads they are traveling on, right on the highway (8, 18, 19, 30). Figure 3 illustrates the contents of a variable message sign providing accident information in Atlanta, Georgia.

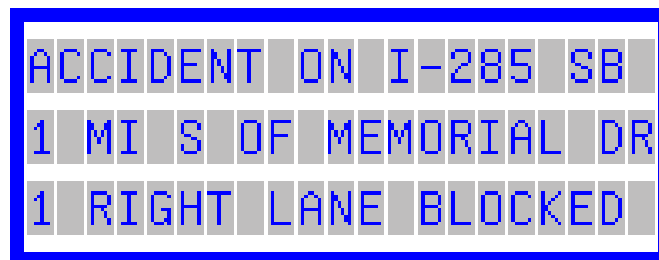


Figure 3. Example of Variable Message Signing

Static Signs

Static road signs are usually implemented to provide navigational information to travelers. When utilized correctly, their legends follow specifications outlined in the Manual on Uniform Traffic Control Devices (MUTCD) and are placed well in advance of key decision points to allow drivers to detect, respond, and decide on appropriate actions. Additionally, color coding for specific facilities or directions is recommended (2). The following figure depicts a static directional sign showing air passengers the appropriate route to parking facilities at Ronald Regan National Airport near Washington, D.C.



Figure 4. Static Signing Directing Travelers to Parking Areas

Highway Advisory Radio (HAR)

Highway advisory radio is a means of disseminating traveler information and advisories to motorists using low-power AM radio signals. Recorded messages, dispatched and monitored by radio personnel, are transmitted via fixed or portable field antennas and picked up on dedicated AM radio stations. The information can be accessed free of charge by anyone who is equipped with a radio and is within the frequency range. Static or variable message signs displaying the HAR broadcast band and mounted flashing lights are used to alert motorists of message broadcasting. Currently, highway advisory radio is used to distribute information on traffic conditions, roadway construction, incidents, and airport parking. However, it can also be used for disseminating travel restrictions, event information, directions, and safety information (21-23).

Internet Service

With the number of computers with access to the Internet having grown exponentially since 1993, the use of the Internet as an information source has quickly become wide-spread. As a result, providing real-time traveler information to a wide variety of people, at any time, for a minimal cost (users pay for their service provider subscription) can ideally be accomplished using the Internet. Interested travelers only need a computer, a modem, and Internet service to gain access. Currently, travelers have 24 hour access to weather forecasts, airport and flight status information, public transit schedules, fares, and routes through a user-friendly graphical user interface. Additionally, a number of state and local transportation agencies have developed web sites in order to distribute real-time traffic information allowing commuters to view graphics and pictures of traffic conditions, which can in turn be used for trip planning. Along with public agencies, independent information service providers such as Microsoft and SmartRoute are also getting involved with traveler information dissemination by setting up traveler information web sites (24-27).

Telephone Information Systems

Telephone information systems have been used to provide travelers with traveler information for some time. This generally inexpensive alternative is low-tech, requiring only a telephone and an easy to remember access number (e.g., 817-1717 for the San Francisco Bay Area). These systems offer several advantages over the traditional radio and television broadcasts as callers can obtain information via a recorded voice message for a particular region, route or location on demand rather than waiting for the next broadcast. Although the

system is easy to use and only requires that the user have a touch-tone telephone, travelers generally consider picking up the phone and placing a call burdensome compared to alternatives that require little to no effort. Additionally, travelers are sometimes worried that the information they receive will be out of date by the time they begin the trip; however, this is less of a concern with the popularity of cellular phones. Currently, traveler information accessed through telephone information systems is free. Most advertising and money making schemes have not worked because of the notion that comparable information is distributed for free over the radio or television (28-30).

In-vehicle Navigation Systems

In-vehicle navigation systems include onboard computers that are used by drivers to obtain driving directions and point-of-interest information visually or audibly while en route. The system consists of a small computer, route selection software, and map-matching software or global positioning satellites to determine the location of the vehicle. Additionally, some systems are able to receive FM subcarrier broadcast signals allowing travelers to access real-time traffic and congestion information. Because of the amount of equipment involved in operation of the system, installation typically costs between \$2,000 and \$3,000. Travelers in the United States have been slow to embrace these navigation systems, but the number installed in vehicles continues to rise, thereby increasing the potential for a reduction in the system's price. Overall, in-vehicle navigation systems are particularly helpful in unfamiliar areas as they increase driver safety and decrease travel time and anxiety caused by the driving task (27, 31).

Commercial Television Broadcasts

Commercial television is used prior to and during regular commute hours to broadcast limited amounts of current traffic conditions on an area-wide basis. The information distributed during these broadcasts come from private traffic reporting companies who use state-of-the-art technologies, aerial surveillance, incident and construction reports, and reports from cellular callers among other means to gather traveler information. This information is then processed into abbreviated traffic reports for dissemination. Because TV air time is expensive, the actual minutes dedicated to traffic information is limited, therefore; very little information can be given and follow-up reports are rarely made, thus affecting the effectiveness of the information. However, commercial television is still a popular means of receiving traveler information because it requires no additional effort, and like HAR and telephone information systems, access is very economical (you just have to pay for the power for the television) (28, 32).

CURRENT APPLICATIONS OF API SYSTEMS AT AIRPORTS

Several airports throughout the United States and Europe have implemented advanced parking information systems in an effort to manage their parking lots, provide relief to crowded access and recirculating roadways, and expedite passenger trips to and from the airport. A discussion of four U.S. airports with existing or planned systems is included in this section.

Raleigh-Durham International Airport

The Raleigh-Durham International Airport (RDU) serves the Research Triangle region of North Carolina. In 1998, the 24 major and regional carriers offering more than 500 daily flights transported approximately 7.2 million passengers. To accommodate originating passengers, which makes up most of the passenger traffic mix, the airport has more than 10,000 parking spaces in one short-term, one long-term, and four remote park and ride lots. However, due to the construction of a new parking garage due to open in 1999, parking near the terminals is limited (Z).

The planned advanced parking information system at RDU will be used to direct passengers to available parking in the first of a four-phase terminal garage plan, which includes 2,700 spaces on 5 levels. The system will consist of two components, a message board placed at the entrance to the garage and variable message signs which are currently located on the main inbound access roadways. The message board will indicate parking space availability (within 5 to 10 percent) for each level based on data gathered using counters and loops embedded in the pavement. As passengers travel up helical ramps, the same information is distributed for the specific level and a gate arm will be lowered, indicating the level is closed if no spaces are available. The variable message signs, which are operated manually, display lot status (e.g., "FULL" or "OPEN") and suggest lower cost alternatives if a lot is full. The parking manager monitors the parking facilities and changes messages using pre-programmed alternatives. Eventually the airport operators want to integrate the access roadway signs with the parking garage signing so that all data collection and parking guidance are done automatically (33).

George Bush Intercontinental Airport (Houston, TX)

George Bush Intercontinental Airport (IAH), located in north Houston, is classified by the Federal Aviation Administration as the 12th busiest commercial airport in the United States. In 1998, the 20 airlines flying to approximately 150 destinations throughout the world served nearly 31 million passengers. Currently, the airport has over 19,000 public parking spaces and ample room to expand depending on customer demand (34).

Travelers approaching IAH can obtain airport-wide parking information by tuning their radio to 530 AM or from an advanced parking information system currently installed in the East and West garages at Terminal C to assist drivers in traversing the 6,500 spaces, six levels, and seven and a half miles of parking aisles. Drivers are alerted to parking availability upon entering the garage in an attempt to assist drivers in finding an available space without repeated circling of the lot and access roadways. A level-by-level sign displays "CLOSED" (level is within 20 vehicles of capacity) and "OPEN" backlit in red and green respectively, depending on the level status. The same system is available for each level, and a gate arm comes down prohibiting entrance into the parking area if no spaces are available. Additionally, the east or west sections of a level can be closed off to help passengers navigate the garage. However, since travel is not permitted between floors, passenger have to exit the garage via payment booths and begin the process over again if they leave a open floor in an attempt to park in another area. Data for the system are gathered using wire sensors embedded in the garage floor to count cars entering and exiting each parking level. This information is used by the central computer to update the information signs. A 5 percent buffer is used in calculating the number of spaces available to account for handicapped and double-parked vehicles. A similar system will be implemented in the upcoming AB parking garage, which is expected to be complete in 2001 (34-36).

Metropolitan Washington Airports (Ronald Reagan National and Washington Dulles)

The Metropolitan Washington Airport Authority maintains and operates Ronald Reagan National (DCA) and Dulles (IAD) airports, which are located just south and west, respectively, of Washington, D.C. Last year, Reagan National Airport served nearly 16 million passengers. To accommodate the 50,000 vehicles that travel on the airport roadway, DCA has parking for nearly 7,200 vehicles. On the other hand, Dulles transported almost 15 million passengers in 1998 and provides parking for 19,000 vehicles (37).

Both airports have existing parking information systems that rely on telephone information systems, highway advisory radio and message signs to disseminate parking guidance. In total, the parking guidance system covers approximately 7,500 spaces including hourly, daily, and remote facilities. At the entrance to each facility and on each level of one of the two parking garages, signs are used to distribute lot status based on availability information collected by counters in lot entrances and exits, and inductive loops embedded in helical ramps. Figure 5 illustrates the use of signing to distribute parking availability information. In addition` to availability information, alternative lot suggestions are displayed by way of neon/fiber optic signs on the exterior of the parking areas. Finally, traveler's may soon be able to access all of this

information from the Internet, as the operators are working towards integrating their Computerized Parking Control System (CPCS) screen with the Authority’s web site (38).



Figure 5. Parking Lot Status Information Dissemination via Message Signs

Summary

This section has provided several examples of airports with an advanced parking information system planned or in place. The details for each system including airport parking and airline passenger statistics, and API system characteristics are in Table 3.

Table 3. Summary of API Systems at U.S. Airports

Airport	1998 Enplaned Passengers (millions)	Total Parking Spaces	Parking Spaces Covered by API	Method of Vehicle Detection	Type of Information Displayed
RDU	7.2	10,000	2,700	Counters/Loops	Level-by-level spaces available
IAH	31	19,000	6,500	Loops	Level-by-level garage status
DCA	16	7,200	7,200	Loops	Level-by-level status at 1 garage
IAD	15	19,000			

SUMMARY OF SURVEY RESULTS

The success of advanced parking information systems is dependent on the motorists’ awareness and use of the information. However, usage of the system is directly related to whether or not drivers receive information they feel is relevant to their decision and how conveniently the information can be obtained. In order to determine the type of parking information drivers need to make parking decisions, their preferred location to receive the information, and the method of receiving the information a survey of 30 Texas Transportation Institute employees who have used parking facilities at various airports throughout the United States was conducted. The results from the user needs survey along with any additional comments provided by respondents are presented in this section. A tabulation of survey responses are included as Appendix B.

Parking Information Desired

Results from the investigation showed that passengers are especially concerned with parking availability and directions to lots when making parking decisions at airports as both of these categories received a rank of one (highly valuable) or two (valuable) from all of the respondents. On the other hand, parking cost and alternative lot suggestions were perceived to have little value by 40 percent and 30 percent, respectively of participants. Other parking information needs receiving high value rankings include method of payment, shuttle times between parking areas and terminal buildings, and any vehicle clearance requirements. Figure 6 illustrates the results of the desired parking information survey question.

These findings appear to be reasonable as they reflect the types of information currently distributed by parking guidance systems that are in place.

Preferred Location to Receive Parking Information

The results from the investigation of preferred location to receive parking information are found in Figure 7. It can be seen from the figure that even though participants could select more than one option, the majority of passengers want to obtain information upon entering the airport property. In fact, 90 percent of the participants responded positively to this location.

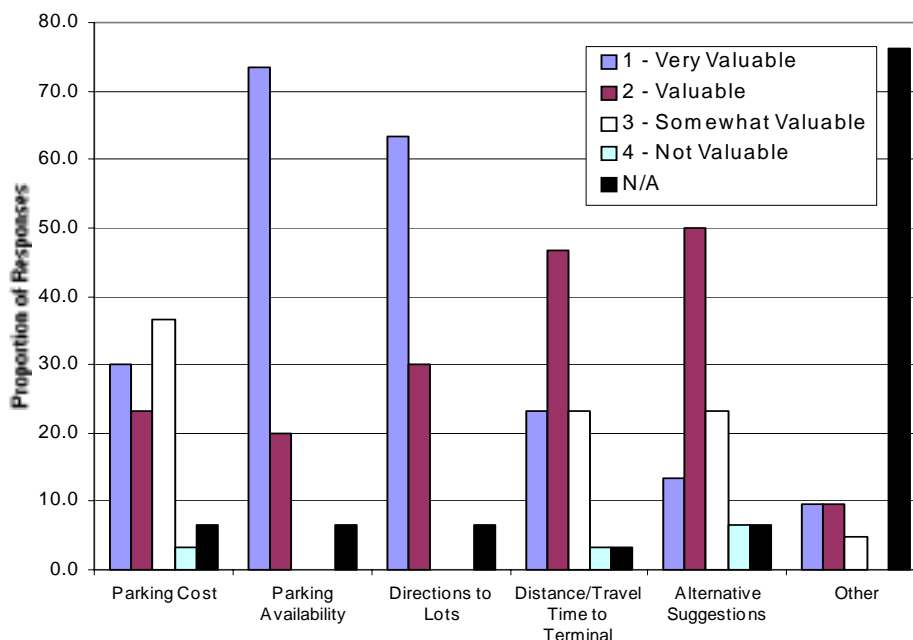


Figure 6. Desired Parking Information Results (n = 30)

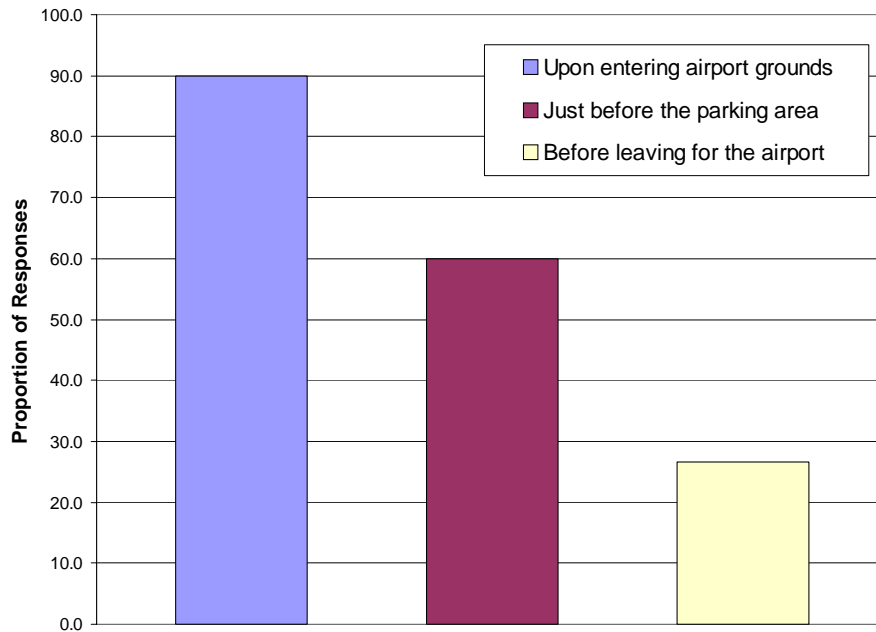


Figure 7. Preferred Information Dissemination Location Results (n = 30)

These results are surprising since previous studies have indicated that travelers tend to feel that information given too early will be stale by the time they need it to make decisions. However, the findings may reflect passengers' desire to obtain guidance information at a location where there is still sufficient time to make an informed decision.

Desired Method of Information Transmission

Figure 8 contains the results from the portion of the study to determine passengers' desired methods for receiving parking information. These findings show that a combination of variable message and static signing would result in the most preferred system. However, radio broadcasts via highway advisory radio and in-vehicle navigation systems may be feasible technologies.

Similar to the parking information desired, the findings regarding the preferred method to receive information seem reasonable since these are the two technologies currently used in advanced parking information systems.

ASSESSMENT OF POTENTIAL ITS TECHNOLOGIES USED IN API SYSTEMS

Seven technologies currently used in providing traffic information were identified as possible methods to disseminate parking information to air travelers. These technologies were researched and evaluated based on the following criteria:

1. Perceived cost of technology to user;
2. What is the timeliness of the information received by the technology; and
3. Does the technology meet the needs of airport users as identified in the survey?

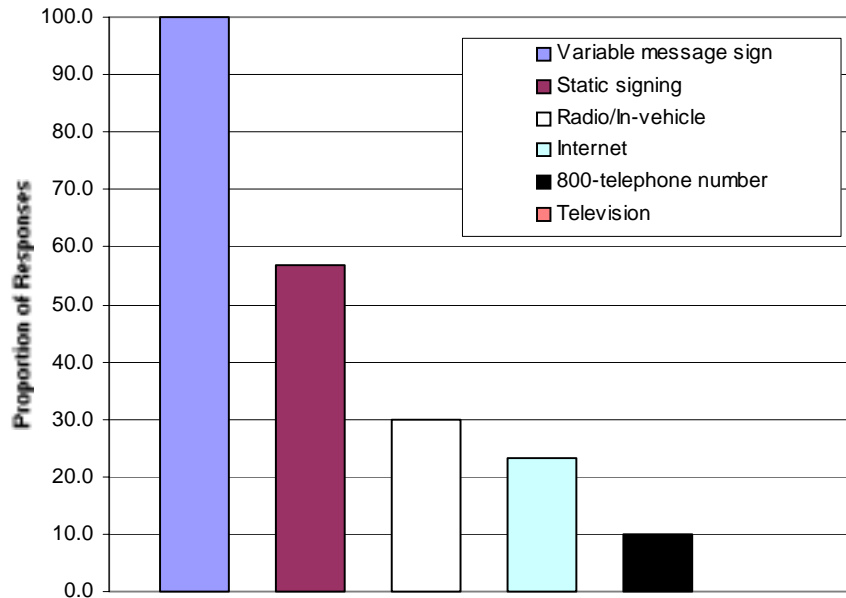


Figure 8. Desired Method for Information Dissemination Results (n = 30)

Table 4 shows a summary of the assessment results. By examining the table, it can be concluded that use of television broadcasts, an 800-telephone number and the Internet to distribute parking guidance information would not promote use of the system. First, each technology reported low acceptance rates in the user survey. Additionally, they all provide pre-trip information, which has the potential to be out dated by the time the passenger gets to the parking lot entrance. Finally, in the case of the Internet, there is some level of cost associated with obtaining the information. A better system design would include technologies that minimize user cost and the possibility of outdated information, yet have a high degree of user acceptance such as VMS, static signs, and highway advisory radio.

Table 4. Parking Information System Technology Assessment Results

Technology	Cost to User	Timeliness of Information	% Survey Participants Willing to Use
VMS	None	En-route	100
Static Signs	None	En-route	56.7
Highway Advisory Radio	None	En-route	30
In-vehicle Navigation	High	En-route	30
Internet	Moderate	Pre-trip	23.3
800-Telephone Number	None	Pre-trip/En-route	10
Television	None	Pre-trip	0

The use of a cellular phone to access an 800-telephone number logically appears to be an acceptable way to receive parking information; however, the 800-telephone number received a low percent willingness to use

by survey participants. This could be attributable to the participant misunderstanding of the survey question, as they thought the telephone information system could only be accessed at home before beginning the trip. Also, a toll-free number could be too long to easily remember and therefore accessing the system could appear burdensome.

GUIDELINES FOR IMPLEMENTING API SYSTEMS AT AIRPORTS

Guidelines to be used by airport parking operators when implementing an advanced parking information system at the airport are developed in this section. These guidelines are designed to ensure that the airport parking system will adequately meet the information needs of air travelers, while maintaining efficient management of the parking facilities. The formulation of these guidelines was accomplished by adopting current strategies used in city-wide parking guidance systems, and adding new strategies to address air traveler information needs and airport parking characteristics identified in this investigation. Table 5 includes a list of the nine guidelines, followed by a description of each guideline.

Table 5. Guidelines for Implementing an API System at Airports

Guidelines
Step 1: Determine which parking facilities are to be included in the advanced parking information system.
Step 2: Identify the parking guidance approach.
Step 3: Divide the global system into zones.
Step 4: Select the information dissemination strategy.
Step 5: Specify system characteristics.
Step 6: Determine the maximum capacity of the parking facilities.
Step 7: Develop and test system software.
Step 8: Deploy the API system
Step 9: Evaluate the API system

Step 1: Determine which parking facilities are to be included in the API system.

A first step in introducing an advanced parking information system to an airport is to decide which parking areas should be covered by the dynamic system. It was shown in Section 3 that airports with multiple parking areas typically have short-term, long-term, and remote lots. An effective API system must provide guidance to as many passengers possible; however, depending on the lot usage and the availability of funds, certain areas may be eliminated from the system altogether or implemented in later phases of a project.

Step 2: Identify the parking guidance approach.

Three potential parking guidance approaches including total-space, zone-specific, and space-specific guidance were introduced in Section 4. Total-space guidance provides the broadest information and is the most economical, while space-specific guidance is the most detailed and can be expensive. Airport operators

can choose the appropriate guidance approach depending on the airport's budget and desired level of information to be given to passengers.

Step 3: Divide the global system into zones.

The use of parking zones in an overall parking information system facilitates the movement of vehicles by allowing for more specific guidance without overloading travelers with information. Additionally, search times can be reduced as passengers are directed to by-pass entire zones that are fully occupied. Once the boundaries of the system are specified and the guidance approach is selected, the areas should be divided into zones depending on the layout of the airport and parking lot. Guidance systems utilizing the total space strategy will require that zones are specified based on the location and the function of the parking area, most likely following the hourly, daily, and remote designations as well as the division by terminal area (e.g., Terminal A and hourly parking). A system built on zone-specific or space-specific guidance will require that zones be established based on lot location and function, and then further divided by level for multi-level garages or area for large surface lots.

Step 4: Select the information dissemination strategy.

Descriptive and prescriptive methods are two broad strategies used in information dissemination. Descriptive parking information systems provide drivers with as much information concerning the parking areas as possible. As a result, these systems increase the choices for drivers and allow them to make decisions. On the other hand, prescriptive parking guidance attempts to limit drivers' opportunity to exercise choice, thereby leaving decisions up to the system itself. This is accomplished by limiting the information distributed to motorists to include only what is necessary to proceed to the next decision point. A descriptive or prescriptive approach can be selected by airport operators based on their desired level of responsibility in guiding passengers to available parking and the information requested by drivers.

Step 5: Specify system characteristics.

Based on the results from Steps 1 through 4, technologies to be used to distribute parking information and the location of information dissemination should be specified. Section 5 included a detailed summary of seven potential technologies to be used in disseminating parking information. Possible technologies include, but are not limited to highway advisory radio, the Internet, telephone information systems, television broadcasts, variable message signs, static signs, and in-vehicle navigation systems. When choosing system technologies, airport parking managers should select alternatives that address the needs of the airport, as well as reflect preferences of airport users.

Location of information dissemination depends on the display method used. For instance, information gathered using the Internet or the television will only be available before the trip (i.e., at home or in the office); whereas, highway advisory radio, variable message signs, and static signing can be used to deliver parking information en-route. Airport operators should also be careful to ensure the information is distributed when air travelers feel it is helpful and in advance of critical decision points. Examples of critical decision points include locations where roadways diverge toward different terminals and entrances to parking facilities.

Step 6: Determine the maximum capacity of the parking facilities.

Because the successful operation of a parking guidance system depends on its use by air passengers wanting to park, airports need to gain passenger acceptance of the system. Two of the quickest ways to lose passenger confidence are to direct them to parking areas that are fully occupied and to make them by-pass areas that clearly have available spaces. Therefore, a cut-off capacity needs to be established so that the system knows when to close and re-open lots. To account for the difficulty associated in finding the one or two last spaces in a lot, vehicles that are double parked, and handicapped spaces, airport parking facilities

typically operate at practical capacity, between 85 to 95 percent occupancy, during peak periods. For parking guidance purposes, it is recommended that the maximum capacity of a parking lot be set to the total number of spaces in the lot or garage less the average number of vehicles that are expected to arrive in the time it would take a driver to reach the parking lot from outermost airport access point. Therefore, if 5 new vehicles enter a specific lot every 15 minutes, and if the drive time from the airport entrance to that lot is 15 minutes, the maximum capacity of a 1000 space lot is 995 spaces. Although this seems to be a relatively small margin of error for finding an available space, the system uses arrival rates rather than turnover rates, which account for vehicles exiting the parking lot. Any vehicle exiting the parking lot will only increase the number of spaces available.

Step 7: Develop and test system software.

The requirements specified in Steps 1 through 6 will dictate the development of the software used to operate the system. The software will use data acquired from vehicle detection equipment to formulate parking availability information that is then transmitted to dissemination technologies. Since each system is unique, operators of airport parking information systems will have to work with software designers to ensure it is tailored to reflect the requirements of their specific system.

Step 8: Deploy the API System

Once the system approach and characteristics have been specified, the advanced parking information system should be deployed for use by drivers intending to park at the airport. Ideally, the entire system would be implemented at one time; however, staged deployment may be necessary due to financial constraints.

Step 9: Evaluate the API System

To test the effectiveness of the API system, it should be evaluated to determine user awareness of and compliance with the parking information. The change in parking lot occupancy rates and stated preference behavior surveys are two ways to measure the effect of an advanced parking information system. The first method simply monitors an increase or decrease in parking lot utilization to infer the effect of API. Stated preference survey data are collected using survey questionnaires. For the state preference survey, respondents are asked what effect the API system had on their parking choice behavior. Additionally, the survey could be used to check driver awareness of the system or inquire about potential modifications to the system in order to increase its use.

CASE STUDY: GEORGE BUSH INTERCONTINENTAL AIRPORT

This section presents the application of the guidelines developed to illustrate the implementation of an advanced parking formation system that effectively provides guidance to air passengers in making parking decisions. The guidelines are applied to Houston's George Bush Intercontinental Airport as a hypothetical extension to the current parking guidance system available at Terminal C. Additionally, for the purpose of this demonstration, it is assumed that the results from the user needs survey described in Section 6 and the findings from the evaluation of the potential ITS technologies found in Section 7 are representative of the Houston, Texas, population.

The following figure contains a diagram illustrating the parking lot layout in relationship to the passenger terminals at IAH. There are a total of seven lots available to air passengers. Six of them, Terminal A hourly and daily lots, Terminal B hourly and daily lots, Terminal C hourly and daily garage, and Terminal AB daily lot are located near their respective terminal building, while the city lot (not shown in the figure) located at the intersection of JFK Boulevard and Greens Road serves as the remote economy lot.

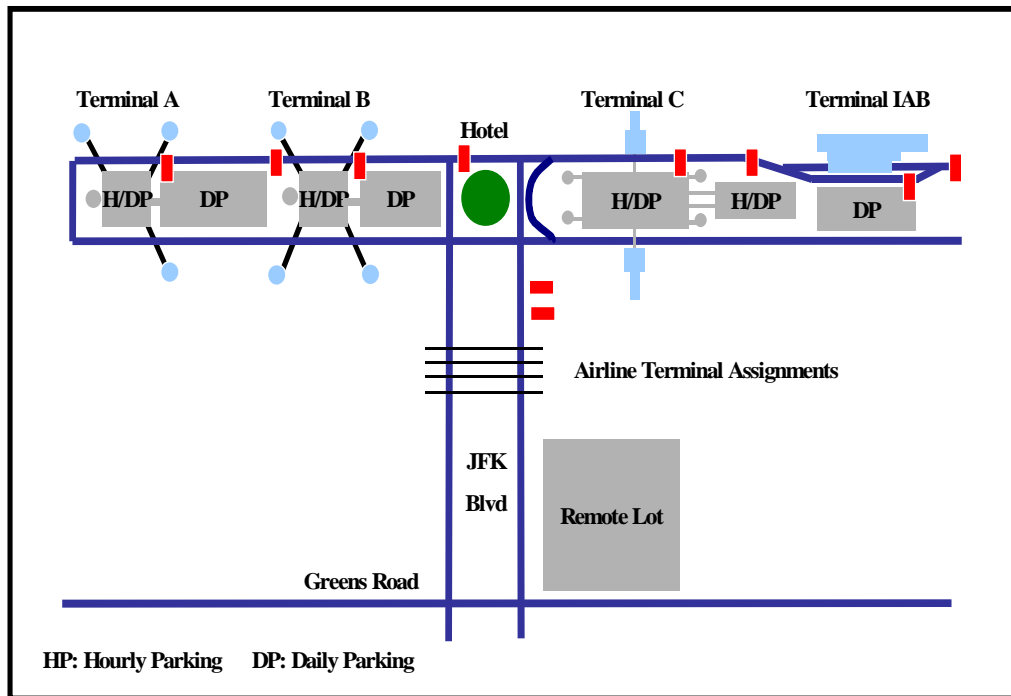


Figure 9. Parking Layout at George Bush Intercontinental Airport

Step 1: Determine which parking facilities are to be included in the API system.

Intercontinental Airport currently has a parking guidance system in place for the Terminal C garage, but has the potential to increase the system to include all seven of the airport parking lots. Although the airport currently provides parking for 19,000 vehicles, the installation of a parking guidance system to cover all the lots is not as intimidating at it first seems since 6,500 of the spaces fall under the control of the existing system. Additionally, the remote lot is not operated by the airport; therefore, the consent and cooperation of the city of Houston is required if this lot is to be incorporated into the system. Ideally, the parking information system would include the remote lot, as it is commonly used as an alternative parking area suggestion. Therefore, assuming the funds are available and full cooperation is given by the city, the expanded advanced parking information system will include all seven lots.

Step 2: Identify the parking guidance approach.

The parking guidance system currently in place in the Terminal C parking garages utilizes a zone-specific approach to provide parking information. The zone-specific strategy is an economical alternative that will allow drivers to reduce parking space search times by bypassing full parking areas. In keeping with the strategies currently in use so as to maintain a homogeneous system and because of the large number of parking facilities and spaces covered by the API system, a zone-specific approach is selected for the airport-wide parking information system.

Step 3: Divide the global system into zones.

Now that it has been established that all seven parking facilities will be included in the parking guidance system and that a zonal approach will be used, the facilities must be broken up into zones in order to provide navigational and availability information. First, the parking facilities are already divided by location and directions are provided through static signing. These zones include Terminals A and B, Terminals C and IAB, and the city lot. The first two zones will be further partitioned into daily and hourly facilities. Finally, if the parking area is a garage structure with helical ramps, the facility will be zoned by level.

Step 4: Select the information dissemination strategy.

Similar to choosing a parking guidance approach, the information dissemination strategy will be selected so that a homogeneous system is maintained. Therefore, a descriptive strategy was selected since the dynamic information signs located at the entrance to the Terminal C garage report parking availability for each level, allowing the driver to decide on which level to search for a vacant parking space. This descriptive approach will be used system-wide in disseminating overall lot status in addition to level by level availability for parking garages.

Step 5: Specify system characteristics.

Based on the assessment of the seven technologies identified as potential methods of disseminating parking guidance information, a combination of variable message signs to provide dynamic parking information and static signs to help drivers navigate the airport access roads was determined to be the most effective information distribution system. This decision is supported by the fact that the selected alternatives are already in use in the existing Terminal C garage system.

The type of information displayed by the signing system depends on the utilization of the facility. This should be kept in mind when designing the information dissemination system. Since people generally want to park as close to their destination as possible, the hourly and daily lots will be used more often than the remote facility. Therefore, signs on the access roadways directing passengers to parking at Terminals A and B, Terminals C and IAB, and remote lots should include static navigational guidance, as well as dynamic information (e.g., lot status or parking availability) for all zones except the remote lot since the remote lot is rarely filled to capacity. As the driver approaches the individual facilities within the zone, static signing should provide directional guidance, while variable message signs continue to alert passenger to the status of the parking area. Finally, when entering the facility, variable message signs at garage structures should display level by level parking information. At surface lots, the VMSs will simply indicate availability information for the entire lot.

In an effort to improve the existing system, the variable message signs on access roadways will only display the lot status as open or closed using backlit green and red letters, respectively, while as the driver approaches the parking area, information on the approximate number of spaces will be distributed. Additionally, a suggestion for alternative facilities will be given as part of the dynamic message when the parking area is closed. Figure 10 illustrates a possible layout and design of variable message signs to provide drivers with parking information and guidance to Terminal C at George Bush Intercontinental Airport.

Step 6: Determine the maximum capacity of the parking facilities.

As suggested in the guidelines, the maximum capacity was set as a function of the number of vehicles arriving during the time it takes a vehicle driving the speed limit to travel from the furthest variable message sign to the parking lot entrance. To determine the arrival rate of vehicles at the various parking lots, vehicle counts were performed at each facility entrance and the 95 percentile arrival rate was used to account for double parking and handicapped spaces. In this system each parking area will have a different maximum capacity, which will have to be factored into the API system software.

Step 7: Develop and test system software.

Software incorporating the requirements specified in the first 6 steps will be developed and tested to ensure accurate availability information will be displayed. The software will collect input data from the lots providing dynamic information, process the availability information, and then transmit it to variable message signs in order to provide drivers with parking guidance on a zonal basis in a descriptive manner.

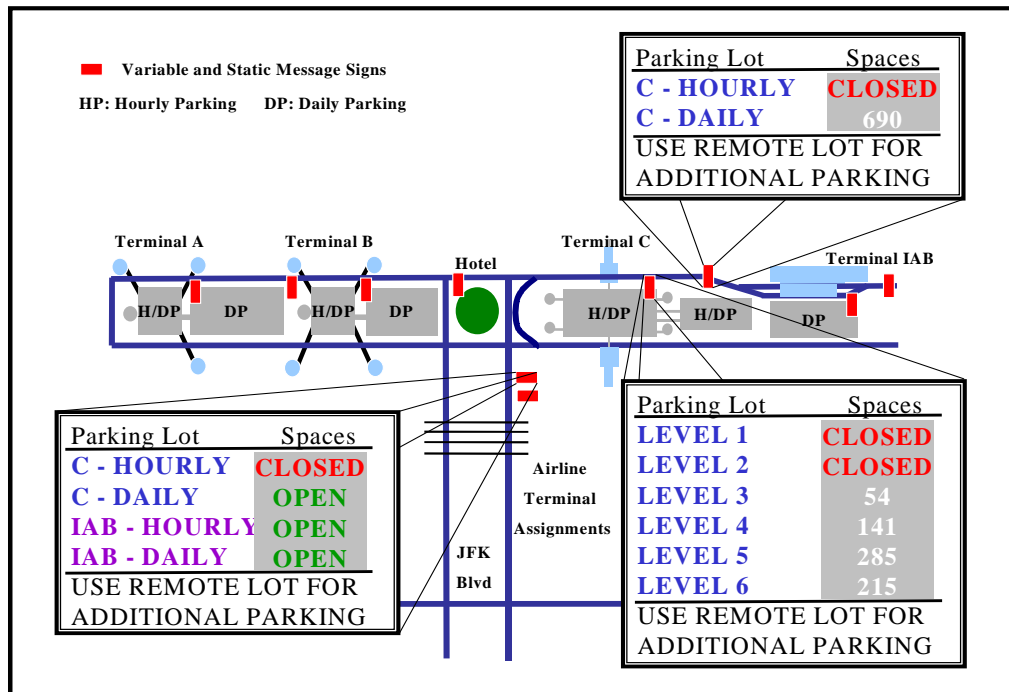


Figure 10. Example of API System at IAH

Step 8: Deploy the API System

An initial survey to determine the parking information needs of motorists intending to park at Intercontinental Airport served as the basis for the development of the API system; however, the extent that the system will actually be used has yet to be determined. Therefore, implementation of the system will be completed and evaluated in phases in order to reduce the initial capital cost associated with deploying the system. In the first stage, an API system serving Terminals C and IAB will be constructed. The second stage will incorporate Terminals A and B into the overall system.

Step 9: Evaluate the API System

Evaluation of the first phase of the system will be completed prior to the commencement of the second phase in order to evaluate its effectiveness in reducing parking search time and congestion on access roadways and at the terminal curbside. The effectiveness will be measured using stated preference surveys that are distributed in the parking areas (most likely on the windshields of parked vehicles) and mailed back to the airport authority for analysis. Based on the results of the survey, modifications to the system will be made in order to improve it or the second phase will be deployed such that all drivers will have the benefit of advanced parking information.

CONCLUSIONS

Airport landside access facilities are beginning to experience more congestion as the popularity of air travel has and continues to rise. Passengers using their personal automobile as a means of conveniently accessing the airport are faced with longer delays in finding available spaces, thereby contributing to the number of vehicles on airport roadways as they circle trying to find an open parking bay. Utilization of advanced parking information systems to provide passengers with accessible and accurate parking availability and routing information at critical decision points results in a decrease in parking search time, reduces roadway and parking facility congestion, and encourages efficient use of parking areas.

When designing parking guidance information systems at airports, it is important to consider the needs of the patrons using the information as well as requirements specified by the operators of the system since voluntary compliance directly affects the success of the system. Results from a survey conducted as part of this research showed that drivers intending to use airport parking facilities feel that parking availability and directions to open lots are the most valuable pieces of information when choosing where to park. Additionally, the survey concluded that a combination of variable message signs, static signing, and possibly highway advisory radio are the preferred methods to receive the desired information. Finally, it was determined that air travelers would like to receive parking information when they enter the airport grounds.

The guidelines developed for implementing an advanced parking information system provide a means for airport operators to install a system that effectively manages parking facilities in an efficient manner while getting passengers into and out of the airport as quickly as possible. The guidelines were applied to Houston's George Bush Intercontinental Airport in order to illustrate the implementation process, which can be used by any airport with parking congestion.

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APPENDIX A: SURVEY QUESTIONNAIRE

Dear Airport Traveler:

This survey is being conducted as part of a research project to determine your airport parking information needs. So that you may be better served, please take a few minutes to answer the following questions. Your cooperation in this effort is greatly appreciated. All information you provide will remain strictly confidential.

1. Please indicate the number of times you parked at the following types of parking facilities in the last 12 months.

Short-term _____ Long-term _____ Satellite/reduced rate _____

2. Please rate the following types of parking information according to your perceived value -(1 = highly value, 4 = not valuable)

___ Parking cost ___ Distance/time from parking to terminal
___ Parking availability ___ Alternative parking lot suggestions
___ Directions to parking lots ___ Other _____

3. When would you like to receive parking information? Check all that apply

- Before leaving for the airport When entering the airport grounds
Just before entering the parking area

4. How would you like to receive airport parking information? Check all that apply

- Radio/In-vehicle Variable message signs
Static signing Internet
800-telephone number Television

5. Please list three airports where you have experience in parking, and indicate the level of difficulty you experienced in finding a parking space.

Table with 4 columns: Airport Location, Not Difficult, Somewhat Difficult, Very Difficult. It contains three rows of empty lines for input.

In the space provided below, please feel free to give us any general comments concerning your parking information needs as an air traveler.

Three horizontal lines for providing general comments.

That completes this survey. Your time and effort are greatly appreciated. Thank you again.

APPENDIX B: SURVEY DATA

Question 1:

Number of times parked in the last 12 months				
	0-2	3-5	6+	Total
Short-term	19	5	6	30
Long-term	28	2	0	30
Satellite/reduced rate	27	3	0	30

Question 2:

Parking information ratings (number of responses)						
	Very Valuable	Valuable	Somewhat Valuable	Not Valuable	N/A	Total
Parking Cost	9	7	11	1	2	30
Parking Availability	22	6	0	0	2	30
Directions to lots	19	9	0	0	2	30
Distance/travel time to terminal	7	14	7	1	1	30
Alternative suggestions	4	15	7	2	2	30
Other	2	2	1	0	16	21

Question 3:

When would you like to receive parking information? (number of responses)	
Before leaving for the airport	8
Just before the parking area	18
Upon entering airport grounds	27

Question 4:

How would you like to receive airport parking information? (number of responses)	
Radio/In-vehicle	9
Information message sign	30
Static signing	17
Internet	7
800-telephone number	3
Television	0

Question 5:

Ease of parking at various airports (number of responses)							
Airport	Not Difficult	Somewhat Difficult	Very Difficult	Airport	Not Difficult	Somewhat Difficult	Very Difficult
DFW	3	2		SEL		1	
IAH	4	8	1	MCO		1	
CLL	6	1		BZN	3		
HOU	4	1		SMF			1
ATL	3			MCI	2		
GSP	1			MSY	1		
DIA	3			ANC	1		
BWI		1		CMH	4		
IAD	1	1		BUF	1		
AUS	4			CVG	2		
PHL		1		PHX		1	
SAT	1			TPA	1		
KUL	1			DAY	1		
CLT	2			CAE	2		
AGS	2			PIT		1	
JNB		1					

Additional Comments:

- Give shuttle times between parking and terminal buildings (mentioned twice).
- Parking should be cheaper.
- More curbside pick-up and drop-off spaces.
- Give proximity of parking to each airline.
- Just point me in the right direction and tell me where the empty spots are. Price doesn't really matter since I just spent \$300 for a ticket, what's another \$20?
- I like the idea of variable message signs at the entrance to the airport grounds. In car radio, the Internet, etc. is too difficult to follow, and the Internet will be outdated. I think the parking areas need better pavement markings.
- Air travelers need to be informed of available spaces before they get to decision points.
- I like to use satellite parking for trips longer than a couple days, and I like knowing how much that parking costs and where it is located soon after entering the airport grounds.

**DEBBIE BURDETTE**

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**METHODS FOR THE DEVELOPMENT AND USE OF A TRAFFIC
VIOLATION DATABASE TO ENHANCE SAFETY ENFORCEMENT EFFORTS**

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SUMMARY

The objective of this research was to document the process and equipment needed to build and operate a traffic violation database that would allow law enforcement to scientifically document problem locations to more efficiently and effectively deploy their resources. The database would be capable of archiving violation data related to red-light running, highway-railroad grade crossing gate violations and speeding.

Designing, developing and implementing the traffic violation database system involves assembling a collection of resources including; software, hardware, capital, staff and training. These resources must then be integrated in an effective and efficient manner. Implementation of a traffic violation database system can be accomplished in several ways, from developing and operating the entire system in-house to outsourcing key components to independent contractors. Outsourcing could be in the form of installation and maintenance of hardware to custom database creation. Twelve essential steps were identified in the development and successful operation of a traffic violation database.

Law enforcement agencies from 29 states were contacted and asked to participate in a survey. Responses were received from ten law enforcement agencies in eight states. Eighty-three percent of respondents indicated that a traffic violation database would address an existing need at their agency. All of those 83 percent indicated that this system would assist in identifying problem areas and allow deployment of manpower based on objective data. Eighty-three percent of respondents indicated that this type of system would become a regular/integral part of their enforcement activities, while only 17 percent indicated that it would only be used in special situations.

The basic structure of the traffic violation database was based upon the results of the law enforcement survey. The survey indicated that the traffic violation database should: operate on a Windows platform; allow data to be published to the Internet; allow data to be input both automatically and manually, and utilize a relational type database with indexed searches. For the traffic violation database to operate as a true relational type database, a large amount of information must first be entered. This information includes geometry, traffic control, signal timings, current ADT, and police jurisdiction. Historical data indicating the violation rate, accident rate, 85th percentile speed, and ADT must also be included. Both custom and prepacked database programs are available for use as the traffic violation database.

It is recommended that two rectangular inductive loops should be used in all lanes of interest at an intersection to detect violations. Two inductive loops allow a minimum speed threshold to be used to avoid erroneous detections. These inductive loops should be placed between one half and five meters apart from front to back and should be located near the stopbar. At highway-railroad grade crossings one inductive loop should be placed downstream on the crossing. This detector would only detect the passage of a vehicle. The inductive loop should be placed in an area where there are no driveways or turning traffic, only vehicles driving around the gates should be registered by the inductive loop. Both installations require a processing unit to accompany the detection equipment. This processing unit must be custom made and allow a remote access connection data downloading. This processing unit would be wired into the signal control at the intersection or highway-railroad grade crossing. This would allow the system to become active only when violations could occur.

Speed trailers should be used to record speed violations throughout the city street system. The speed trailers should use laser radar to detect vehicle speeds, along with a reader board to display the vehicle's speed. The laser radar also needs to be accompanied by a processing unit that would determine if the vehicle is in violation of the speed limit for that particular street. This processing unit only needs to be capable of manual data downloading.

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INTRODUCTION

Automated enforcement is defined as the use of technology to capture images for the purpose of monitoring and enforcing traffic control laws, regulations, or restrictions (1). The image capture technology negates the need for law enforcement to directly witness the event when enabling legislation has authorized its use. Numerous legal and social issues surround the use of automated enforcement and limit its attractiveness as a cost-effective solution. Opponents argue that automated enforcement violates personal privacy and constitutional rights for the sole purpose of generating revenue. These programs are seen as a dishonest form of enforcement that is less effective than traditional enforcement efforts.

In a highly litigious country, such as the United States, where citizens' rights are held to the highest regard, innovative solutions that do not violate the perceived constitutional rights of motorists must be found to help mitigate traffic violations. Testimony given in 1997 by Ricardo Martinez, the Administrator of the National Highway Traffic Safety Administration, estimated that in recent years one-third of all crashes and two-thirds of the resulting fatalities could be attributed to aggressive driving behavior (2). A reduced presence of law enforcement on our nation's roadways is thought to contribute to, if not encourage, aggressive driving. However, the limited financial resources available to law enforcement agencies prohibit an increased presence.

Problem Statement

Historically, automated enforcement has been based on an all-or-nothing approach with little to no regard for the officer responsible for conventional enforcement. The social climate of today severely limits the acceptance of technology as an alternative to law enforcement. A public opinion poll conducted in 1989 by the Insurance Institute for Highway Safety indicated that 58 percent of respondents approved of automated enforcement and 35 percent disapproved (3). Although opponents are outnumbered, they are still capable of prohibiting or discontinuing automated enforcement programs by lobbying elected officials or encouraging motorists to contest mailed citations in court. Law enforcement estimates that if two percent of traffic citations issued were contested in court, the extra burden on the judicial system would be overwhelming (4). Automated enforcement may be inevitable in the future. However, cost-effective, non-invasive solutions exist today that would enhance the current capabilities of law enforcement. A simple, yet highly effective alternative to automated enforcement would incorporate technology into law enforcement activities to enhance their capabilities without sacrificing the objectiveness of the officer in the field.

Research Objectives

The objective of this research was to determine the process and equipment needed to build and operate a traffic violation database that would allow law enforcement to scientifically document problem locations to more efficiently and effectively deploy their resources. The database would be capable of archiving violation data related to red-light running, highway-railroad grade crossing gate violations, speeding and high-occupancy vehicle lane violations. Data would be collected using key components of existing automated enforcement systems. Once a problem has been clearly documented, it can be used to describe traffic violation problems and demonstrate the need for more enforcement to legislators, city government and the general public. States that currently have enabling legislation for automated enforcement, as well as those that do not, would benefit from the ability to report on trends in violations over time. In order to prove the validity of the traffic violation database, the findings and recommendations of this study are applied in a general sense to the city of College Station, Texas.

Scope

The scope of this research was limited to the conceptual development of a traffic violation database and the supporting technology needed to gather the data. As indicated in the problem statement and research objective, this system should be structured around law enforcement capabilities and constraints. The study focused on alternate means of existing technology to enhance the enforcement capability of officers in the field. The scope of this paper was limited to red-light running, highway-railroad grade crossings gate violations and speeding.

Work Plan

In order to accomplish the research objective outlined in this proposal and to provide a thorough understanding of the issues related to enhanced enforcement, the following tasks were completed.

Task 1: Review Literature

A literature review was performed in order to examine previous research and issues related to automated enforcement. Specifically, case studies documenting the use of automated enforcement technology in the United States and its application to typical law enforcement. Legal and social issues that prohibit the use of automated enforcement technology were also identified.

Task 2: Develop Law Enforcement Survey

A telephone and fax-back survey was constructed to elicit specific information regarding the use and acceptance of technology in enforcement and the structure of the proposed traffic violation database.

Task 3: Administer Law Enforcement Survey

The survey was administered in fax-back form to law enforcement personnel throughout the United States. Law enforcement contacts were gathered from Federal Highway Administration (FHWA) Demonstration Project No. 86 - Incident Management Workshop sign-in sheets. Additional contacts were also obtained from mentors and various Texas A&M University staff and Texas Transportation Institute employees.

Task 4: Develop Traffic Violation Database Concept

Using the results of the law enforcement survey and literature review, the structure of the traffic violation database was determined. This included determining what technologies can be used to gather, transmit, store and display the traffic violation data to law enforcement personnel in accordance to law enforcement desires. The environments in which the database will function was also determined.

Task 5: Apply the Traffic Violation Database Concept

In order to prove the validity of the traffic violation database, the findings and recommendations of this study were to be applied conceptually to the city of College Station, Texas. Problem locations were to be identified through the help of the College Station Police Department and the appropriate technologies, as determined by the study, were to be described for each location in terms of installation, data collected and potential benefits. The hypothetical application was also to describe what information police officers in the College Station Police Department would want from each problem location and how it would be utilized to more effectively and efficiently deploy their resources. Since contacts with the city of College Station were not obtained, this task was pursued in a general sense.

BACKGROUND

Enforcement of traffic laws is the primary means through which hazardous driving behavior can be controlled. Maintaining a strong police presence on city streets and roadways has traditionally been used to enforce traffic laws. However, during the past two decades, the number of licensed drivers, vehicles and vehicle miles of travel (VMT) have increased steadily. According to the Federal Highway Administration, the total number of licensed drivers in the United States in 1997 was 179,539,340. There are roughly 880 licensed drivers to every 1000 persons of legal driving age. The total number of all licensed publicly owned, private and commercial vehicles, including motorcycles is 210,236,393 (5). The ability of law enforcement to respond to these rising demands has clearly diminished over the years.

A 1992 survey conducted by the Insurance Institute for Highway Safety showed police enforcement resources in relation to need from 1978 to 1989. The findings from 33 states showed only a 6 percent increase in the number of officers whose duties included traffic law enforcement, while the number of licensed drivers increased almost 19 percent. The number of traffic officers per million licensed drivers fell approximately 11 percent while the annual number of miles traveled increased 38 percent (6). This suggests that a more efficient and effective allocation of resources is needed to maintain the integrity of traffic law enforcement. The National Highway Traffic Safety Administration (NHTSA) reports that approximately 66 percent of all annual traffic fatalities are caused by aggressive driving behavior such as red light running and speeding (7).

Automated Enforcement

Automated enforcement was previously defined as the use of technology to capture images of license plates and drivers for the purpose of monitoring and enforcing traffic control laws, regulations or restrictions. Automated enforcement systems typically consist of three key components, the detection equipment, a processing unit and a camera to record the violation. In states where enabling legislation has been enacted, this image capture technology negates the need for law enforcement to directly witness a violation.

Red Light Running

Enforcing red-light violations at intersections has become one of the most common uses for automated enforcement. Traditional enforcement methods for red light runners are limited in efficiently addressing the increasing frequency of aggressive drivers. Red light violations are easily discernable and perhaps the least ambiguous traffic violation. Yet, the United States has been relatively slow to embrace the idea of automated enforcement. However, it appears that automated enforcement technologies have been used abroad for a number of years and have proven to be effective and reliable.

Detection equipment typically consists of buried loops or piezo sensors. These detectors are typically placed at or near the stop bar to detect approaching vehicles and vehicle speeds. Once the traffic signal has switched to the red phase, the camera used to record the violation becomes active. A small period of time and a preset speed are incorporated into the system to differentiate turning vehicles and vehicles coming to a stop. If both of these criteria are exceeded the image capture device records an image. Image capture devices can either be standard 35 mm cameras or digital image processors. The following are brief descriptions on several red light running automated enforcement programs throughout the world.

Victoria, Australia

Australia has used automated enforcement for red light violations since 1979 (8). Red light cameras were introduced in Victoria to reduce the number of collisions occurring as a result of motorists disobeying traffic control signals. After an initial six month trial period in 1981, ten red light cameras were purchased by the Road Traffic Authority and first used on August 16, 1983. The number of cameras has progressively increased to 35 which are rotated through 132 sites within the Melbourne metropolitan region.

New York, New York

New York, New York currently has the largest and oldest automated enforcement program for red light runners in the United States. The New York City Department of Transportation had been researching automated enforcement technology since 1983. Program success in countries like Europe and Australia prompted the City of New York to conduct a demonstration project to prove the red light running technology. Through the demonstration of the automated enforcement technology the Department of Transportation was able to gain the support of the City Government and begin the Request For Proposal (RFP) process. However, no public education campaign was undertaken and no advance warning was given as to the placement of the cameras (9).

A contract was awarded to Electronic Data Systems by the City of New York on the premise that the cost of the system would be offset by ticket revenue. The total price for the three and a half year contract was \$13,900,000 (10). This contract was awarded after the State of New York passed a law allowing the use of automated enforcement technology for red light violations. Privacy issues were raised during the programs inception and subsequently only the registered owner of the vehicle can be cited because photographs are taken of the rear license plate (9). Initially, 20 locations were selected for camera installation. These twenty locations were determined by using accident information and contacting local police precincts to identify locations that were receiving special attention (9). Since the inception of the program, violations at intersections with automated enforcement technology have decreased by 20 percent.

Polk County, Florida

In September of 1994 Polk County, Florida began using automated enforcement technology for red light runners as part of a Federal Highway Administration demonstration project. The demonstration was conducted at four intersections in several different environments in Fort Meade, Haines City and Lakeland (11). A public education campaign was initiated with funding by the Federal Highway Administration to reinforce the problems associated with red light running. This program followed the recommendations given in the Red Light Running Program Strategic Planning Guide by Plosky (12). Since Florida does not currently have enabling legislation to allow citations to be issued, warning letters are mailed to drivers who are caught running red lights. Statistics are not currently available on the effectiveness of the system in terms of violation reductions (1).

Howard County, Maryland

Howard County has completed phase I of a Federally funded demonstration project to test automated enforcement systems for red light violations. This program demonstrated the feasibility and reliability of photographic based surveillance systems to detect and record red light violations at problem intersections. The use of the cameras was in response to the high cost of traditional enforcement methods and a rising need for enforcement at intersections. A significant public awareness campaign was undertaken through numerous media outlets. Signs were posted on roadways that contained cameras but the exact intersection where the camera was placed was not publicized. During the test period, warning notices were sent to the registered owner of the vehicle. As a result of that study, legislation was passed by the 1997 Maryland General Assembly, House Bill 391, that authorizes law enforcement to use such automated enforcement technology to enforce traffic laws at signalized intersections. The program was implemented on February 3, 1998, with two cameras. The 20th camera became operational in November 1998. In 1998, violation rates at the monitored intersections were reduced by an average rate of 48 percent (13).

Phase II of the demonstration project began in 1998 with plans to demonstrate the feasibility of digital red light running automated enforcement systems. Vendors in Australia, Great Britain and Israel are participating in the demonstration and installation of digital camera systems at four sites has begun. Digital cameras can

electronically transmit pictures to a central computer for identifying owners and issuing notices. The most important benefit will come in the form of time and manpower savings as the cameras no longer need servicing on a daily basis (13).

Montgomery County, Maryland

Montgomery County is participating with Howard County in testing the feasibility of digital camera technology. The first camera was installed in the Bethesda area and the Police Department and the Department of Public Works and Transportation are currently working to identify locations for future installations. Initially, warning notices will be sent to violators during a test period. Following the test period tickets will be sent to violators. The fine is \$75.00 and no points will be issued against the vehicle's owner. Failure to pay a ticket can result in the inability of the vehicle's owner to renew his/her driver's license or vehicle registration (14).

Oxnard, California

The automated enforcement of red light violations began in Oxnard, California on April 4, 1997. The program began to combat the growing number of red light violations and the need for 24-hr enforcement. The program was initiated with 15 intersection approaches. A public education and awareness campaign was initiated to inform the public about the purpose of the automated enforcement program. California Vehicle Code SB833 authorizes the city of Oxnard to use automated enforcement technology with frontal photography to identify both the driver and the vehicle. Results of this enforcement effort could not be obtained (1).

Charlotte, North Carolina

In 1998, Charlotte became the first city in the state of North Carolina to implement an automated enforcement program, called *SafeLight*, for red light violations. The North Carolina State Legislature ratified enabling Legislation in 1997 and the Charlotte City Council approved the program in 1998, paving the way for automated enforcement technology to be used at signalized intersections. Charlotte contracted with Lockheed Martin IMS and in July of 1998 the first two cameras were installed. Eighteen more cameras were added in September. All the cameras are located at high accident locations and crashes were reduced by 32 percent on the monitored approaches (15).

Speed Limit Enforcement

Automated speed limit enforcement is one of the earliest automated enforcement applications in the United States and abroad. Traditional enforcement methods for enforcing speed limits are limited in their ability to efficiently address the increasing frequency of aggressive drivers. Automated speed limit enforcement is considered by many to be the most controversial type of enforcement due to the variability associated with setting speed limits (1). However, it appears that the use of automated speed limit enforcement is on the rise.

Speed enforcement systems usually consist of a radar device, a processing unit to identify violators and a camera to identify the vehicle. When the processing unit determines that a vehicle is exceeding a preset speed, an image is recorded with either a standard 35 mm camera or a digital image processor. Pertinent information regarding the violation is also superimposed upon the image. Automated speed limit enforcement equipment may be installed in a stationary vehicle, portable trailer, tri-pod, or it may be mounted in a self-contained cabinet to a pole.

Speed limit awareness programs are also gaining popularity at home and abroad. These programs use radar device to measure speeds and an electronic display panel to provide the speed to the passing motorist. Speed

trailers are mobile roadside devices that measure and display the speed of a passing vehicle. Speed trailers include a radar device to detect and measure the speed of a passing vehicle, as well as a display board which displays the speed of the detected vehicle and the legal speed limit of the roadway. Usage of speed trailers had grown steadily since their development in the late 1980's. In late 1998 500 devices were in operation across the United States.

Speed enforcement trailers have been used to enhance typical officer enforcement. However, they have typically been used as a public education device. Speed trailers are also used for automated enforcement purposes in a few states. When the speed trailer is used for automated enforcement purposes an image capture device is installed which takes a picture of a vehicle if it is above a predetermined threshold. This image is typically stored internally and downloaded through a modem connection or manually in the field (18). The following are brief descriptions of automated speed limit enforcement programs throughout the world.

Edmonton, Alberta

In 1987, the Edmonton Police Service began exploring using photo radar. Between 1987 and 1993, the Edmonton Police Service evaluated several photo radar systems for future use. It was decided that photo radar would be an effective way to conduct enforcement and improve officer safety. A secondary benefit would be the reduced number of officers needed for traffic enforcement. The system became operational and enforcement officially began in March 1993. A second unit was introduced in 1997. The photo radar units are housed in two unmarked police vehicles. The Edmonton Police Service estimates that they would need over 30 police officers to maintain the current level of enforcement without the use of the two photo radar units. The photo radar units are used at high speed locations, high collision locations, areas of heavy traffic volume and school zones. Also, the photo radar units can be used to deal with citizen complaints about speeding vehicles in their communities, as well as to monitor traffic in those areas (16).

Victoria, Australia

Photo radar enforcement began in Victoria in 1989 with the introduction of 54 speed cameras. The photo radar units are mobile and are operated by the Victoria Police. The Traffic Camera Office (TCO) was established in 1990 to administer the program. Other automated enforcement efforts in Victoria were also consolidated into the TCO. This consolidation effort was essential to the continued success of the programs. The high level of enforcement provided by the Victoria Police and the TCO is intended to modify driving behavior and reinforce the perception of strict enforcement. Since the program was initiated in 1989 the total number of accidents decreased by 22 percent (1).

National City, California

Photo radar enforcement began in National City in 1991 with the introduction of one camera. This camera was mounted in a mobile vehicle and rotated among 90 enforcement locations. This program issues the ticket to the driver of the vehicle, not the registered owner. This requires the owner of the vehicle to identify the driver in the event he/she was not driving. If the owner does not identify the driver the case is thrown out of court due to a loophole in California law. In a six year period from 1991-1997 the number of accidents decreased by 51 percent (1).

Paradise Valley, Arizona

In 1987, a legislative change enabled the City of Paradise Valley to pass a city ordinance allowing the use of photo enforcement for speed limit violators. The program began using manned automated enforcement equipment to enforce speed limits at approximately 60 locations throughout Paradise Valley and has grown

from there. The threshold for violations occurs at 125 percent of the posted speed. This program is the longest running operation in the United States and is credited with substantial accident reductions (17).

Grade Crossings

Automated enforcement of highway-railroad grade crossing violations is one of the newest forms of automated enforcement. A typical system provides surveillance of one or more traffic lanes on one or both approaches. Inductive loop detectors are used to detect vehicles weaving through the gates. A connection between the control circuitry of the highway-railroad grade crossing allows the system to activate itself and await violations. Video, digital image processing or a standard 35 mm camera are used to provide images of the violations. Pertinent information relating to the time of the violation, the location of the violation, and the gate, signal and train operation are superimposed onto the image. The following are brief descriptions of grade crossing automated enforcement programs throughout the United States.

Jonesboro, Arkansas

The first United States installation for automated enforcement at highway-railroad grade crossings was demonstrated in the City of Jonesboro, Arkansas in 1991. This system consisted of field equipment along with a direct telephone link to playback equipment in the Jonesboro Police Department. Police viewed the transmitted images and determined if a citation was warranted. Approximately a year and a half after the project began, the transmitted images were no longer of suitable quality for use as evidence due to equipment and maintenance problems. As of 1998 the system is still not operational but the City of Jonesboro remains optimistic that the system will be operational in the near future. No studies were conducted to determine the effect of the system on accident reduction. However, it is believed that the crossing was safer when the system was operational (1).

Los Angeles, California

In 1992, the Metropolitan Transit Authority began five demonstration projects to determine the feasibility of using automated enforcement equipment at highway-railroad grade crossings. Citations were issued in three of the five demonstrations projects. Large reductions in the number of grade crossing violations were seen at each test site after the installation of the equipment. Based on the positive results of the five demonstration projects, the Metropolitan Transit Authority decided to proceed with the installation of automated enforcement equipment at 17 crossings. The Metro Blue Line Grade Crossing Safety Program was initiated in 1993 by the Los Angeles Metropolitan Transit Authority. The program was designed to discourage and prevent illegal movements being made by vehicles at both gated and non-gated grade crossings (19).

Ames, Iowa

An automated enforcement system became operational in Ames, Iowa in 1996. The need for automated enforcement was sparked by concern for motorist safety and a lack of cooperation on the part of the railroad to install a four-quadrant gate system. A digital image capture system was used to photograph the violation. However, Iowa state law requires that the driver of the vehicle be identified and that the citation cannot be delivered through the mail. Thus, it was required that an officer hand deliver the citation to the home of the driver. During July of 1997 through September 1998, the system was taken off-line to upgrade the detection and image capture equipment. This was hoped to resolve problems associated with identifying drivers at night, as well as license plate legibility (1, 20).

Texas

In 1995 the Texas Legislature passed Senate Bill 1512 which required the Texas Department of Transportation to conduct an automated enforcement demonstration project at a highway-railroad grade crossing. Automated enforcement equipment was installed and demonstrated at three crossings with automatic gates. The equipment photographed, either on 35 mm film or as a data file, vehicles violating the gate arms. This program successfully demonstrated how automated enforcement equipment can be used to record violations and identify the license plate and owner of the vehicle. It did not demonstrate the process of issuing citations or examine implementation efforts (20).

Law Enforcement

Interest in automated enforcement equipment has been building for a number of years. Experience with automated enforcement equipment in other countries has provided a basis for a number of programs operating in the United States today; all of which would not exist without the cooperation of law enforcement agencies. A study conducted by the National Highway Traffic Safety Administration (NHTSA) in the mid 1980's dealt with field testing automated enforcement equipment by three state police agencies (21). The law enforcement personnel involved in the study generally thought that automated enforcement was a worthy concept and were in favor of implementing a speed enforcement program using the equipment. However, interest in the use of automated enforcement equipment diminished after the study was completed and other enforcement needs arose. Again, interest was expressed in the use of automated enforcement technology in late 1989 and another report by the NHTSA documented the experiences of eight police departments across the United States. Most indicated that automated enforcement was a viable alternative to traditional law enforcement (17).

Increased efficiency in terms of processing citations and resource deployment was a theme common to all the automated enforcement programs outlined in the literature review. The law enforcement agencies in these areas were no longer able to provide the necessary enforcement to ensure a safe city street system. Thus, automated enforcement technology was seen as a tool to broaden their capabilities without increasing their presence. Programs that initiated public education/awareness campaigns appeared to be more successful and have a more favorable public opinion.

However, not all law enforcement agencies support the use of automated enforcement equipment. Tom Wagoner, Chief of Police for the city of Loveland, Colorado decided against using photo radar because he felt it ultimately undermines respect for the law and police officers. "It's just not our style, we want our officers to have a personal relationship with our citizens, and I think that if people started receiving tickets in the mail, it would be perceived as some sort of fundraiser. You can give out ten times as many tickets with photo radar, but I think that it angers as many people as it pleases (22)."

Legal Issues

Currently, only 20 states have installed some form of automated enforcement equipment. However, all 20 states do not have enabling legislation that allows automated enforcement. Enabling legislation is necessary to uphold constitutional, state and local standards. A growing interest in the use of automated enforcement technology prompted the Institute of Transportation Engineers' (ITE) Traffic Engineering Council to form a committee to gather and disseminate information on the use of automated enforcement technology (23). As of November 1998, ITE has adopted Policy G-9 regarding automated enforcement (1):

Enforcement: "It is the policy of ITE to encourage and support enforcement of traffic laws and regulations, and obedience of traffic control devices where such devices are implemented under

proper guidelines, to promote safety, to maintain operational efficiency, and generate respect for traffic control devices.”

Facilitating Enforcement: “It is the policy of ITE to support enforcement by using, among other methods, automated enforcement techniques that use image-capturing technologies to identify illegal driver behavior. Further, the support for automated enforcement is subject to effective measures being taken to protect the privacy of vehicle occupants, prompt notification of alleged offenses, due process being available to alleged offenders, and the use of the collected data being restricted to law enforcement purposes.”

Numerous case studies both in the United States and abroad have proven the effectiveness of these technologies. However, strong opposition surrounding the use of automated enforcement has centered on issues such as ticket revenue distribution, ticketing procedures and their effectiveness, associated costs and the right to privacy. ITS America adopted the *Interim ITS Fair Information and Privacy Principles* in 1996. This document provides guidance on how to implement ITS technologies while respecting individual privacy. However, these principles recommend against the use of advanced technologies for enforcement purposes (24).

The legal issues surrounding the use of automated enforcement are rooted in the rights guaranteed to the citizens of the United States by pertinent amendments to the Constitution. The First and Fourth Amendments deal with the right to privacy. Currently, there is no court case that has defined a person’s right to privacy with respect to operating a vehicle under the First Amendment. However, several Supreme Court decisions have been used to assert that automated enforcement technology does not violate an individual’s right to privacy because the vehicle they are operating is in public view and on a public roadway (1).

The Fourth Amendment states that a person has the right to freedom from unreasonable searches and seizures. Again, the Supreme Court has ruled that the Fourth Amendment is based on a reasonable expectation of privacy. Since the individual is traveling in view of the public on a public road they should have no expectation of privacy. Thus, several legal experts have concluded that automated enforcement technology does not violate an individual’s rights under the Fourth Amendment (1).

Concerns regarding due process and equal protection deal with the Fifth and Fourteenth Amendments. In order for an automated enforcement program to issue tickets under the Fifth and Fourteenth Amendments the citations must be sent in a timely manner. Reasonable notification should also be given to the public to warn that automated enforcement technology is in use and citations are being issued. Citizens must also be provided the right to declare their innocence and present a defense and view the evidence prior to appearing in court. The right to present a defense is provided to an individual by the Sixth Amendment (1). Most legal experts believe automated enforcement of traffic laws does not violate the constitutional rights of a citizen. However, the perceived violation of an individual’s rights is just as damaging as an actual violation.

Automated Enforcement Opponents

Privacy and loss of individual freedoms are major concerns to a somewhat small, but extremely vocal group of citizens. Public education campaigns on the documented success of automated enforcement efforts does little to persuade these individuals of their merits. These groups of individuals can hinder the ability of a city or state to pass enabling legislation allowing the use of automated enforcement. They can also hamper the effectiveness of programs that are already operational. Organizations such as the National Motorists Association (NMA), founded in 1982, are dedicated to protecting the rights of motorists and have lobbied successfully on local, state and federal levels (25). NMA opposes all camera-based law enforcement and is working toward a ban on its use in all of North America. NMA is funded entirely through membership dues by individuals, families and small businesses. NMA provides a number of services to its members including legal services aimed at successfully contesting a camera-based citation. They stress that all citations received

through an automated enforcement program should be contested, if for no other reason than to overload the court system (25).

Another organization that is based in Canada but fundamentally opposes the use of automated enforcement is the Society for Safety by Education Not Speed Enforcement (SENSE) (26). SENSE provides many of the same resources as the NMA. They are also a strong and successful lobbying group that disseminates information to the public and elected officials on the dangers of automated enforcement. They also stress the importance of contesting all citations issued under an automated enforcement system. As stated previously, law enforcement estimates that if two percent of traffic citations issued were contested in court, the extra burden on the judicial system would be overwhelming (4).

The City of Glendale, Arizona is carefully examining alternatives to photo radar as an enforcement tool for speed and accident reduction. For more than three years, the city's traffic engineers have been studying the traffic volumes and accident rates at major intersections. They have scientifically documented these statistics at major arterial streets and residential streets in Glendale. It is the goal of the city, through increased education and enforcement, to gain voluntary compliance from drivers to obey existing speed limits and traffic regulations by providing them proof of their actions, not implementing a system that may not be warranted (27).

The American Automobile Association (AAA), a powerful lobbying organization with millions of member across the United States also opposes the use of some forms of automated enforcement. Art Kinsman, an AAA government-relations staffer in Massachusetts, indicated AAA has always been opposed to roadside surveillance and citation without contact with an actual police officer. "The lack of a face-to-face meeting with a police officer results in an inability to face one's accuser. It also makes it more difficult to come up with an adequate defense should an individual choose to fight it in court. In the long run, we feel that it undermines respect for traffic laws as well as police officers (22)."

The traffic violation database concept could be used to counter claims by these types of organizations that automated enforcement is solely a revenue generating venture. Scientifically documenting problem areas, along with public education and awareness efforts could form the basis by which further automated enforcement efforts could build. If it could be shown that these enhanced enforcement methods and public education campaigns were not adequate to deter violators then the process of passing legislation and gaining public support wouldn't be as difficult.

LAW ENFORCEMENT SURVEY

Survey Design

The first step in the creation of a traffic violation database was to design the law enforcement survey. Two objectives were identified in the design process. First, each respondent will be able to complete the survey within 10 minutes and second, easily understand all questions presented therein. Given the limited amount of time available to complete this research, these requirements were essential in ensuring adequate response by law enforcement personnel. The law enforcement survey was constructed to be administered by telephone or in a fax-back format. The survey was designed to elicit specific information regarding the use and acceptance of technology in traffic enforcement, as well as to help determine the process and equipment needed to create a traffic violation database. The six areas of inquiry identified for the survey were as follows:

- Potential application/acceptance of the traffic violation database;
- Perceived benefit of the traffic violation database;

- Computer capabilities of the agency and officer;
- Current methods for deploying resources in the field;
- Ability to use historical violation data as a public relation/education tool, and
- Specific information of use to officers in enforcing traffic law.

Survey Administration

The survey was to be administered to law enforcement personnel who worked in a traffic enforcement division. It was hoped that one response could be obtained from each state in the continental United States. However, this goal was not achieved due to the limited amount of time available to complete the survey. Law enforcement contacts were gathered from sign-in sheets for FHWA Demonstration Project No. 86 - Incident Management Workshop. Additional contacts were also obtained from CVEN 677 Mentors, Texas A&M University staff, Texas Transportation Institute (TTI) employees and the Internet. However, everyone contacted requested that the survey be faxed to their office so they could review its content before proceeding. Law enforcement agencies from 29 states were contacted and asked to participate in the survey. Responses were received from 10 law enforcement agencies in 8 states. Responses by state can be seen below in Table 1.

Survey Results

Thirty-seven surveys were sent to law enforcement agencies in 29 states. Of those 37 surveys 12 responses were returned from 10 different law enforcement agencies. The following is a list of the 10 responding agencies:

- Beaverton Police Department – Beaverton, Oregon;
- Bryan Police Department – Bryan, Texas;
- Carlsbad Police Department – Carlsbad, California;
- Casper Police Department – Casper, Wyoming;
- Cheyenne Police Department – Cheyenne, Wyoming;
- Lincoln Police Department – Lincoln, Nebraska;
- Montrose Police Department – Montrose, Colorado;
- Norfolk Police Department – Norfolk, Virginia;
- Prescott Police Department – Prescott, Arizona, and
- San Antonio Police Department – San Antonio, Texas.

A copy of the survey that was used to elicit the 12 responses is in Appendix A. The survey began with a brief introduction to the database concept. Eighty-three percent of the 12 respondents indicated that this type of system would address an existing need at their agency. The majority of those 83 percent indicated that this type of system would assist in identifying problem areas and allow deployment of manpower based on objective data. Eighty-three percent of respondents indicated that this type of system would become a regular/integral part of their enforcement activities, while 17 percent indicated that it would only be used in special situations. Again, the majority of those 83 percent indicated that this type of system would be an integral part of traffic enforcement. Ninety-two percent of respondents indicated that this type of system would influence decisions on where to conduct enforcement activities. The majority of those 92 percent indicated that this type of system would allow them to identify problem areas and deploy their manpower accordingly. Respondents were then asked where their agency would experience benefits in enforcement efficiency and/or effectiveness from this type of system. One hundred percent of respondents indicated a benefit in manpower utilization, 67 percent indicated a time savings, 17 percent indicated a benefit in equipment utilization and 8 percent indicated possible benefits may come in the form of additional, or alternate, traffic control devices.

Respondents were asked about their computer skills, as well as the computer capabilities of their agency. Forty-two percent of respondents indicated their agency currently used DOS based programs. Forty percent of those 42 percent indicated they were comfortable in using DOS based programs. One hundred percent of respondents indicated their agency currently used Windows based programs. Seventy-five percent of those 100 percent indicated they were comfortable using Windows based programs. Ninety-two percent of all respondents indicated their agency currently had Internet capabilities with a browser. Eighty-two percent of those 92 percent indicated they were comfortable using the Internet.

Respondents were asked how their agency typically establishes an intersection, grade crossing or segment of roadway as a problem location. Fifty percent of respondents indicated that their agency uses current violation rates. Ninety-two percent of respondents indicated their agency uses accident rates. Seventy-five percent of respondents indicated their agency uses the opinion of the public to establish problem locations. Sixty-seven percent of respondents indicated problem locations are determined by personal observation. Thirty-three percent indicated other methods of identifying problem locations, which included information from the traffic engineering office as well as special situations like construction activities.

Respondents were asked to indicate how their agency currently makes decisions on where and when to deploy their resources. Seventy-five percent indicated they utilize citizen input or complaints in deploying resources. Fifty percent of respondents indicated their agency uses some form of accident statistics in deployment. Twenty-five percent of respondents indicated their agency uses their local traffic engineering office, personal observation, and/or violation rates to help in deployment decisions. Eight percent of respondents indicated that past enforcement efforts and experiences are used in deployment decisions.

Respondents were asked how useful they felt a system that could historically document traffic violations to be in educating the public or city officials on law enforcement concerns. One hundred percent of respondents indicated that the system would be beneficial in some form. It was indicated that such a system would be useful in educating the public on problems within the local city street system from a traffic enforcement point of view. One respondent felt it would be beneficial to display current violation rates on a web page. The ability to show historical, objective data was also cited as an important feature of the system.

Respondents were asked how much time per week they would be willing/able to spend manually entering information into the system. Twenty-five percent indicated they were unwilling or had no time available to manually enter information. Eight percent indicated they could spend one hour per week. Seventeen percent indicated they could spend two hours per week. Eight percent indicated they could spend three hours per week. Twenty-five percent indicated they could spend four hours per week. Eight percent indicated they could spend five hours per week. Eight percent indicated they could spend more than six hours per week entering data into the system. A common comment regarding data entry was that clerical staff should be required to perform data entry in most circumstances.

Respondents were asked what information they would like to be able to easily access regarding a specific location or street in terms of enforcing traffic laws and regulations. Sixty-seven percent indicated the number of violations, 42 percent indicated time and date of citation, 25 percent indicated number of accidents, 25 percent indicated number of speeders, 25 percent indicated the location of the violation or accident, 17 percent indicated the traffic volume, 17 percent indicated the type of citation, 17 percent indicated the speed of the roadway, and 8 percent indicated contributing factors.

TRAFFIC VIOLATION DATABASE

Instead of relying on automated enforcement to alleviate engineering or educational problems, agencies looking to automated enforcement should first consider a more contemporary approach that balances engineering, education and enforcement. Instead of pushing for a fully automated enforcement system, law

enforcement agencies and local government should consider enhancing traditional enforcement methods through the use of existing technology.

Any agency interested in correcting a problem must first identify and scientifically document the problem to assure the problem is real and not perceived. The traffic violation database concept is a tool for identifying and documenting problems related to red light running, speeding and highway-railroad grade crossing gate arm violations. It is the first step in what *may* evolve into a fully automated enforcement system. However, this information should first be used to address educational problems or alleviate engineering deficiencies thereby negating the need for automated enforcement. Law enforcement agencies may be capable of continuing conventional enforcement if their efforts can be targeted at those areas where problems are real and can be documented. In today's ever changing technological climate, it is easy to overlook some of the more simple solutions that can be applied nationwide without the benefit of legislative action.

Conceptual Design

Designing, developing and implementing a traffic violation database system involves assembling a collection of resources including; software, hardware, capital, staff and training. These resources must then be integrated in an effective and efficient manner. Implementation of a traffic violation database system can be accomplished in several ways, from developing and operating the entire system in-house to outsourcing key components to independent contractors. Outsourcing could be in the form of installation and maintenance of hardware to creating a customized database. If the entire system is to be built and operated in-house, appropriate staffing and training should be accomplished. For the equipment to be effective, a thorough understanding of the detection equipment must be obtained.

Just as it is important for the public to be informed about the implementation of any new enforcement program, law enforcement agencies and related personnel must be provided the necessary support, training and supervision to ensure successful operation of a traffic violation database. Training for all individuals who have access to the traffic violation database should be completed before the system becomes operational. This will ensure the success of the system through proper operational methods.

Database Structure

The basic structure of the traffic violation database was determined from the results of the law enforcement survey. The survey results indicated that the traffic violation database should:

- Operate on a Windows based platform;
- Allow data to be published to the Internet;
- Allow data to be input automatically, as well as manually, and
- Utilize a relational type database with indexed searches.

The basic structure of the traffic violation database is illustrated below in Figure 1. For the traffic violation database to operate as a true relational type database, a large amount of information must first be entered. This information can be entered all at one time or on a location by location basis as more detection equipment is put in the field. The information that is critical to the operation of the traffic violation database includes:

A list of all streets that are to be monitored;

- Roadway data relating to the highway-railroad grade crossing, intersection or section of roadway. This includes the geometry, traffic control, signal timings, current Average Daily Traffic (ADT), and police jurisdiction (if the database will be linked to multiple jurisdictions), and

- Historical roadway data indicating the violation rate, accident rate and historical ADT of the highway-railroad grade crossing, intersection or segment of roadway. This database should also give the 85th percentile speed for all roadways.

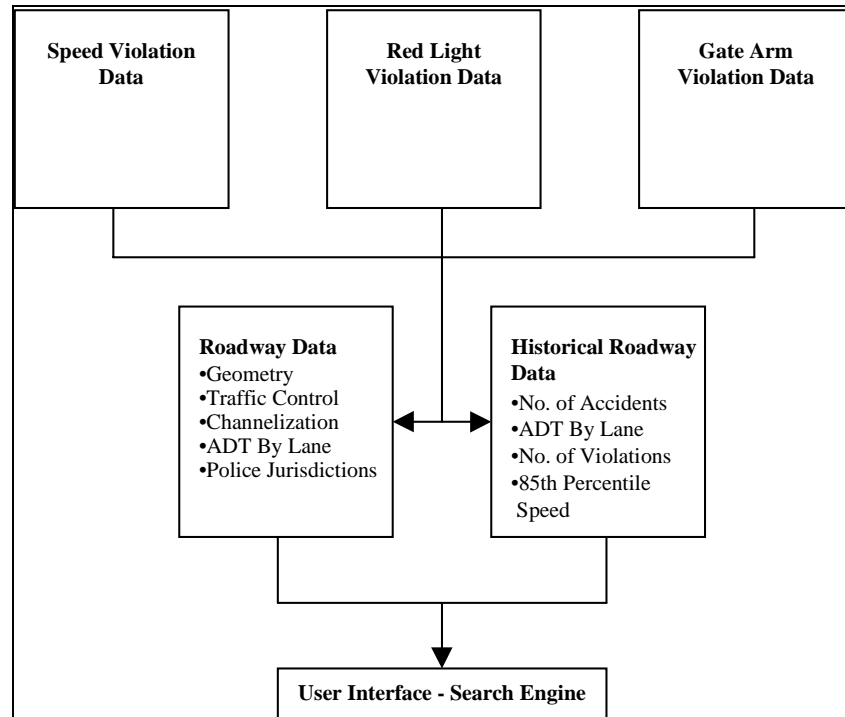


Figure 1. Relational Database Concept

In the law enforcement survey, respondents were asked what information they would like to be able to easily access regarding a specific location or street in terms of enforcing traffic laws and regulations. Sixty-seven percent indicated the number of violations, 42 percent indicated time and date of citation, 25 percent indicated number of accidents, 25 percent indicated number of speeders, 25 percent indicated the location of the violation or accident, 17 percent indicated the traffic volume, 17 percent indicated the type of citation, 17 percent indicated the speed of the roadway, and 8 percent indicated contributing factors. Since this system will be used by law enforcement agencies, it is important to provide the information they have requested.

It may be possible to import this information from an existing database maintained by local police, the highway patrol or a state department of transportation. However, this would depend upon the sophistication of the original database and its compatibility with the traffic violation database. Importing this information may not be appropriate if the traffic violation database will only be used to monitor a small number of locations, as the volume of information may be prohibitive. Once this information has been entered into the database, the detection equipment may be brought on-line and violation data can be accumulated.

Software

The concept of the traffic violation database was to create an effective and efficient means of deploying law enforcement resources at minimal cost. Thus, it was important to identify software packages that offered

the desired features at a reasonable price. A database is a collection of tables and descriptions. The database describes the properties, rules, views, connections and stored procedures of the tables. In a database, design features allow you to create, add, modify and remove tables, relations, views, connections, rules, triggers and procedures. The descriptive information that is entered about each intersection, grade crossing or segment of roadway would be contained in different tables. The violation data for each location would also be contained in these tables. It is the function of the database to provide a relational link between certain fields or sets of data. Relations can be one-to-one or one-to-many. This simply means when one item is indicated it is related to one other item or several other items. Combinations of these relations allow many-to-many relations to be obtained and provide a truly relational database.

Several prepacked software programs are commercially available for creating large relational databases. One program of note is Microsoft's Visual FoxPro. Visual FoxPro can be used for data retrieval, manipulation, querying and reporting. It is also capable of storing vast amounts of data and batch processing. Visual FoxPro components can be used to build high-powered Internet database applications which allows publication of data to the Internet. The Traffic Law Enforcement division of the Texas Department of Public Safety uses Visual FoxPro to manage accident data from across the State of Texas (28).

Software can also be specially designed to meet the specific needs of the traffic violations database. Several software companies that will take your specifications and create a relational type database application that provides indexed searches on a Windows platform. They can also integrate web publishing capabilities into the software. These programs all allow some or all of the data to be published to a website on the Internet.

Violation Detection - Intersections and Highway-Railroad Grade Crossings

In order to be able to detect a traffic violation, some mechanism must be in place to accurately determine if and when a violation occurred. Detection equipment can be simple or extremely complex. The type of violation being detected determines the equipment to be used. The detection equipment is the means through which the recording equipment in an automated enforcement system is activated when a violation occurs. In this application, the detection equipment is used only to detect and record that a violation has occurred. The traffic violation database is not used to issue citations or warnings. Thus, image capture technology is not needed to record the violation. This greatly reduces the cost per intersection of this type of system. This not only reduces the amount of hardware needed in the field it also reduces the overall size of the traffic violation database. For the traffic violation database concept the detection equipment must be relatively inexpensive, dependable and durable. It should be noted that pedestrian and bicycle violations are not included in the traffic violation database.

Air Tubes

Air tubes are one of the simplest and most inexpensive triggers available. Air tubes can be used to detect the passage of vehicles and can also be used to determine vehicle speeds. However, air tubes should not be used for detecting violations due to their limited life.

Piezoelectric Sensors

Piezoelectric sensors can be secured to the roadway in order to detect vehicles that violate the traffic control device. When a vehicle crosses the piezoelectric sensors it is compressed and generates a voltage that then is used to trigger a timer. Two piezoelectric sensors can be used to measure speed. While piezoelectric sensors can be very accurate, they are also sensitive to excessive vibration. As with the air tubes, piezoelectric sensors are inexpensive and are secured to the road and are exposed to moving traffic. Thus, piezoelectric sensors should not be used for this application.

Laser Detectors

Laser technology is typically used in conjunction with digital image capture technology as an alternative to loop detectors. Laser technology is expensive and provides a level of sophistication that is beyond the capabilities of the traffic violation database concept. A number of high resolution traffic cameras incorporate laser technology into the camera itself.

Video Loops

Video loops are a recent development in triggering technology. Video loops make use of a computer to create a virtual loop on the image of an intersection. Changes in each frame are compared to predefined screen areas and used to trigger devices such as counters and cameras. These systems are capable of detecting traffic in multiple locations within the camera's field-of-view. These systems are marketed for use in highway management, ramp control, vehicle counts as well as enforcement. The major benefit of using video loops is that they do not require any cuts to be made in the roadway. The cost of installing video loops is equivalent to other detection equipment when eight or more lanes or traffic are to be monitored at one location (29). Thus, these systems can be considered for use with the traffic violation database when the location being monitored has more than eight lanes.

Inductive Loops

Vehicle detection systems frequently combine a digital loop detector and an inductive loop embedded in the roadway. The combination of these two components provides a highly sensitive field for detecting vehicles within the detection zones. A rectangular loop detector zone is typically used to assure the magnetic field is equal throughout the zone. This configuration has proven successful in detecting and photographing vehicles that are running a red light or going under or around a rail crossing arm during the red signal sequence. Thus it holds that this system would be an effective tool in detecting violators. A fully-functional inductive loop is basically no better than more sophisticated and expensive detection equipment such as video loops and lasers (30). Thus, this system would be an effective detection device to be used with the traffic violation database.

This detection system allows the direction and speed of vehicles traversing the loops to be monitored. When used at highway-railroad grade crossings or intersections, directional sensitivity can be useful in assuring a vehicle actually committed a violation and not a legal maneuver. Speed sensitivity also allows for a minimum speed threshold to be defined. This is important to distinguish vehicles that are resting on an inductive loop or making a right hand turn during a red phase at a signalized intersection from a vehicle violating the red light. Inductive loops are fairly inexpensive and dependable. However, correct installation is critical to insure reliable operation. Placement, choice of materials and thorough testing are also very important to reliable operation.

Inductive loops are usually placed one half to five meters apart from front to back. The distance between the loops depends upon the anticipated speed of the roadway. Inductive loops should also never be placed closer than one meter apart from side to side. Inductive loops for use with higher speed traffic are usually placed further apart. Standard six foot diamond or round loops are not suitable for automated enforcement detection. These are the standard shapes for traffic monitoring when only simply presence detection is required. However, smaller loops are more effective for passage detection and thus used for automated enforcement (31). Thus it is assumed that this would hold true in the traffic violation database concept. Accurate detection is required to maintain the integrity of the traffic violation database.

Earth Magnetic Loops

Another type of loop available for use with traffic violation database is the Earth Magnetic Loop (EML) made by 3M. Unlike surface or buried loops a small hole is drilled into the pavement into which the EML is placed. These may be useful in situations where other loops already exist or extensive cuts are not advised or feasible. The EML transforms changes in magnetic field intensity into inductance changes which can be sensed by loop detector units. EML are intended for point detection applications. One, two or three earth magnetic loops installed across a lane will replace a typical three- turn, six foot wire loop. Earth magnetic loops will usually not work in the vicinity of large metal objects and thus would not be suitable for applications near rail lines (29).

Violation Detection - Speed

There are several systems on the market for electronically enforcing speed laws. The most common is radio detection and ranging (radar). While, radar is the most used detection device in the enforcement of speed laws, there are other effective methods. One product exists which uses reflected light as a trigger. This electro-optic technology cannot be detected or jammed. It is also not subject to interference, and can detect two vehicle speeds when they are next to each other. Another alternative to traditional radar is laser radar. This system measures speed, distance and direction by using an extremely narrow beam width. Laser radar provides a higher degree of accuracy than traditional radar systems. The beam from the laser radar can only target one vehicle at a time and minimizes the possibility of false readings (29).

This is the only application of the traffic violation database that is designed to be mobile. Again, the system that will be used to detect speed violations is the same as that used in photo enforcement minus the image capture technology. Typically, photo radar units can be mounted for fixed or mobile deployments. When the equipment is mounted for mobile use it is typically mounted inside a specially equipped vehicle, on a tripod or in a specially designed speed trailer.

On-Site Communication

Intersections and Highway-Railroad Grade Crossings

Once the detection equipment is in place and the database is capable of receiving data, a communication link must be established. When the detection equipment detects a violation a signal must be sent to a processing unit. This processing unit would essentially be a small computer capable of remote access via a telephone modem or manual access through a data port. This device would store data related to the violation, including the time and date of the violation as well as the speed of the vehicle if applicable. This device must also be wired into the signal controller at an intersection or the gate controller at a highway-railroad grade crossing. This would allow the computer to determine when the red phase has begun or if the gates had been lowered. Once this indication is received the computer would start recording violations from the detectors (30). A simple program would need to be written in order to extract the data from the storage device. This program would allow the data to be extracted and automatically imported in the correct fields in the database. Most of the database software listed above has this capability or it could be incorporated into a database that was custom designed.

Speed Monitoring

The detection equipment used to identify a violation must be incorporated into a processing unit. Threshold speed values must be determined for each location where the device is placed. If the detection equipment registers a speed greater than the threshold value the computer will record that a violation has occurred, along with the time, date and speed of the vehicle. Since this detection technology is designed to be mobile the computer only needs to be manually accessible through a data port. The same program that is written to

extract data from the intersections and highway-railroad grade crossings can be used to extract and import the violation data into the traffic violation database.

RECOMMENDATIONS

The recommendations for the conceptual creation and use of the traffic violation database are based upon the information presented throughout this paper. It should be noted that a number of individuals did not respond to the law enforcement survey. In addition no responses were received to a follow-up questionnaire regarding implementation of a traffic violation database were also not received. A number of the individuals contacted in regard to the use and operation of existing automated enforcement systems also did not respond. Thus, the objectives of this research could not be fully completed in the time available to prepare this report.

In order to develop an operational traffic violation database a law enforcement agency must complete twelve essential steps. The twelve steps are listed below:

1. Obtain the cooperation and support of city officials,
2. Identify potential monitoring locations,
3. Determine the type of detection equipment needed for each application,
4. Determine the peripheral hardware that must accompany the detection equipment in the field,
5. Determine the software needed to create, operate and manage the violation data,
6. Determine the equipment and process needed to transfer the data from the field to the database,
7. Determine if the hardware installation, operation and maintenance can be done in-house or will the work need to be contracted out,
8. Install and test all necessary equipment at one site for each type of violation,
9. Assess and complete all necessary changes and complete the full installation,
10. Complete training on the capabilities and proper use of the traffic violation database,
11. Expand the system when feasible to do so,
12. Maintain the equipment.

Each of the twelve steps is important in the successful operation of a traffic violation database. However, only steps two thru six are within the scope of this research and will be discussed below

Location Identification

The law enforcement survey indicated that the majority of agencies typically establish an intersection, grade crossing or segment of roadway as a problem location based on accident rate statistics. These agencies also use current violation rates, public opinion, personal observation and information from the traffic engineering office. This system could be used to monitor locations that have already been established as problem areas or to identify locations that are in need of an increased law enforcement presence. The system can also be used to alleviate or address citizen concerns. A prioritized list of locations for each type of violation detection system should be created and continually updated.

Violation Detection Equipment

Intersections

Two rectangular inductive loops should be used in all lanes of interest to detect violations of the red phase. The placement of the loops depends upon the geometry of the intersection being monitored, the speed of the vehicles traversing the intersection and the presence of other detection devices. The loops should be placed between one half meter and five meters apart from front to back on center. Two adjacent loops should not be closer than one meter from side to side on center. Figure 2 illustrates the placement of the inductive loops

on all approaches to an intersection. The downstream inductive loop should be positioned at or near the stopbar. The exact location will vary from site to site. If there is already a rectangular inductive loop present on the approach for actuated signal control, only one additional inductive loop may be needed. This decision depends upon the type of existing loop, its location and function. Laser detection systems and video loops may be necessary if the existing detection equipment prohibits additional inductive loop installations.

Inductive loops provide accurate detection at a reasonable cost. They are readily available and most city traffic engineers are familiar with their operation. It is also assumed that most city traffic engineering divisions and maintenance personnel have installed inductive loops before. However, the installation and maintenance of the inductive loops may also be contracted out if it is technically or financially warranted. The degree of sophistication in operation and the cost to purchase detection devices such as a laser or video loop make them inappropriate for this application, unless the existing equipment prohibits additional inductive loop installations. The placement of the loops depends upon the geometry of the intersection being monitored and the presence of other detection devices. Figure 2 illustrates the placement when two inductive loops must be installed.

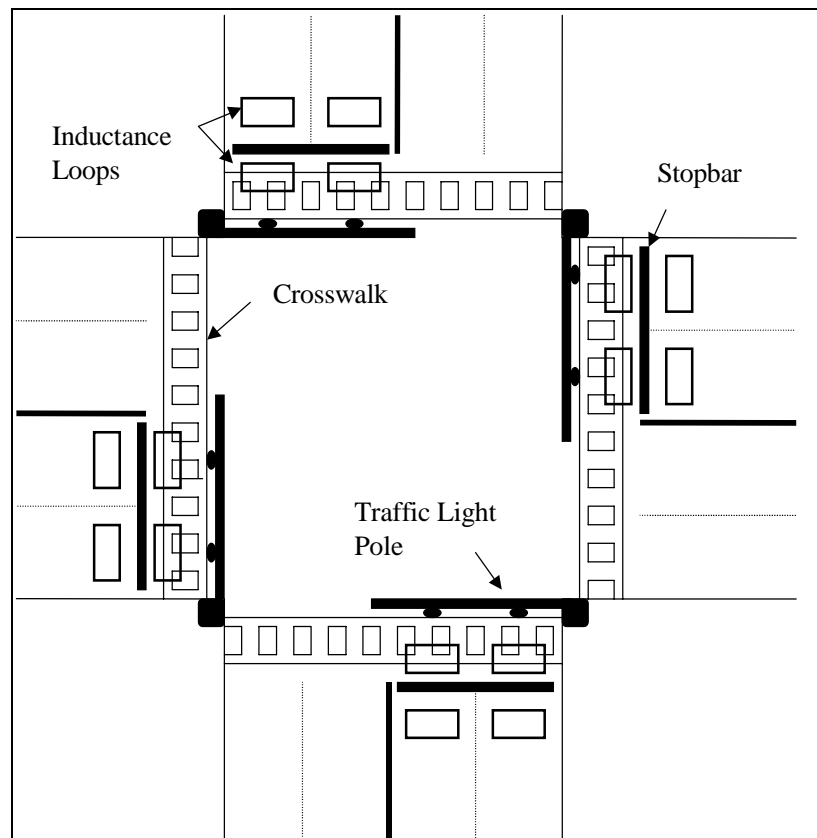


Figure 2. Red Light Violation Detection System

The processing unit that needs to accompany the detection equipment must be custom made (30). This device would allow a dial-up modem to download the stored data to the database. This system would also determine when a detection was a violation. The computer would be wired into the signal control and become active once the red phase had initiated. A buffer must be programmed into the system to allow vehicles to pass through the intersection under an all red condition without detecting the violation. A one second buffer is sufficient for use with the traffic violation database. Also, the speed of the vehicle must be

determined and compared with a preset threshold. A speed of 10 mph will be used as the threshold above which the detection is considered a violation. By allowing a speed comparison vehicles which come to rest on the inductive loops or make right hand turns will not be counted as a violation.

Highway-Railroad Grade Crossings

One digital loop detector and inductive loop should be used on the downstream side of the crossing for the highway-railroad grade crossing application. Figure 3 illustrates the placement of the inductive loop in each travel lane. Depending on the geometry of the crossing, the inductive loop should be placed so that vehicles driving around the gate do not register as a violation. The loops will detect the violators after they have already driven around the gates and are proceeding down the roadway. The inductive loops should also be placed in an area where there are no driveways or turning traffic. The inductive loops are connected to a processing unit that is wired into the gate controls. It will determine when the gates are down and begin to record violations. This processing unit must be capable of connecting to a dial-up modem for downloading the data. It should also have manual download capabilities. As with the intersection application, inductive loops provide accurate detection at a reasonable cost. They are readily available and most city traffic engineers are familiar with their operation. It is also assumed that most city traffic engineering divisions and maintenance personnel have installed inductive loops before. However, the installation and maintenance of the inductive loops may also be contracted out if it is technically or financially warranted. Video loops and laser technology are extremely expensive and for this application may not be able to reliably detect movement through the gates without detecting the train itself.

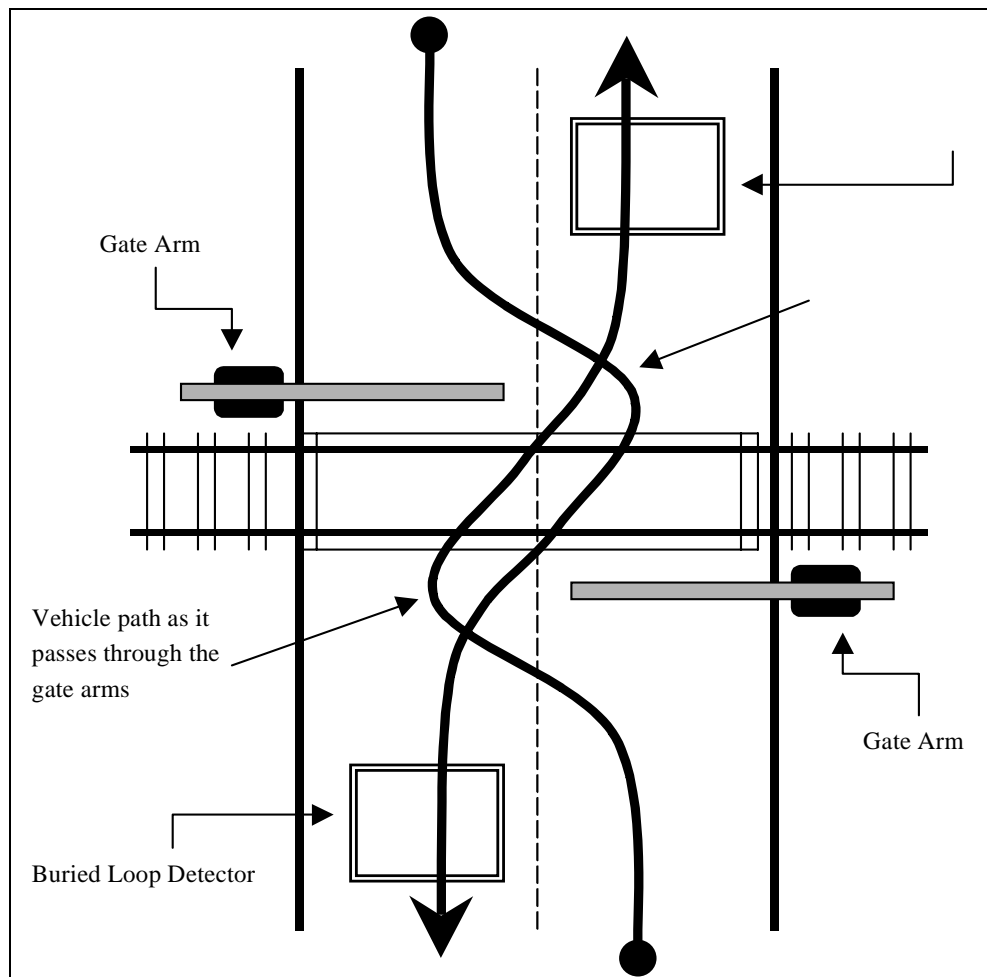


Figure 3. Highway-Railroad Grade Crossing Violation Detection System

Speed Monitoring

Monitoring sections of roadways or spot locations should be done using speed trailers. These devices are truly portable and serve as an educational tool as well. A typical speed trailer is illustrated in Figure 4 below. The technology used to detect vehicle speeds can be either laser or conventional radar. This depends upon the preference and the accepted method for measuring speeds in the city of interest. The speed trailer will have an on-board processing unit that will be used to store the violation data and determine if a vehicle is in violation of the posted speed limit. A threshold value will need to be entered for each location being monitored. This value depends upon the law enforcement agency. The processing unit only needs to be capable of transferring data manually since this device will be moved periodically and an officer can download the violation data after each placement. Most speed trailers usually have a reader board that displays the speed of the vehicle as well as the speed limit of the roadway. This serves to educate the driver as they pass the speed trailer. This is also a key objective of the traffic violation database concept.



Figure 4. Speed Trailer from Montgomery County, Maryland

Traffic Violation Database Software

In order to run the traffic violation database a computer must be available at the law enforcement agency of interest. This computer may be used for other purposes. However, it is recommended that the computer be used only to manage the traffic violation data. If an employee of the law enforcement agency is proficient in the use and creation of databases, Visual FoxPro may be used and training must be provided to everyone who will be using the software. The task of creating the database should be contracted out if no one is

proficient in the use and creation of databases. The memory requirements for each system will depend on the number of locations being monitored and the amount of explanatory information that is required. The computer should be at least a Pentium II, 400 MHz with 64 megabytes of RAM and 10 gigabytes of hard disk space (30).

TRAFFIC VIOLATION DATABASE APPLICATION

The traffic violation database concept was to be hypothetically applied to the city of College Station, Texas. Several attempts were made to contact the College Station Police Department to discuss this hypothetical application. Unfortunately, due to the limited amount of time and resources available to conduct this investigation, it was not possible to identify a list of problem locations in the city of College Station. Thus, the hypothetical application can not be tailored to meet the specific needs of the College Station Police Department. Therefore, the application described in the remainder of this section has been designed to be more generic in nature, and will be applied to the intersection of Texas Avenue and Southwest Parkway in the city of College Station. It should be noted that this intersection has not been identified as a problem area, it is only used as an illustration in the application of the traffic violation database. It should also be noted that no highway-railroad grade crossing within the city of College Station had suitable geometry for the application of the traffic violation database. The following paragraphs describe the process necessary to implement a traffic violation database in the city of College Station and illustrates the equipment needed to detect violations at the intersection of Texas Avenue and Southwest Parkway.

The first step in developing the system is to involve local government in the city of College Station. This will ensure cooperation between law enforcement and city officials. It is then important to determine a source of funding for the creation and operation of the traffic violation database. One aspect of the funding issue is to place a monetary figure on the expected increase in deployment efficiency. It is also important to determine if the detection systems that will be placed in the field can serve a dual purpose.

A list of problem locations must then be compiled. These locations may be identified a number of different ways; accident statistics, personal observation and citizen complaints can all be used. Again, this information was not obtained. However, once this information is gathered, the type and amount of detection equipment and peripheral hardware can be determined. The decision must now be made as to whether the system can be built and installed in-house or if it must be contracted out. This is where the cooperation of the city becomes important. The city traffic engineering office may have the expertise available to complete the design and installation. However, the creation of the database software may still need to be contracted out to a qualified firm. This will ensure the integrity of the data over time.

Once the equipment is purchased installation of the equipment may begin. Again, this can be done in-house or contracted out. While the installation is being completed, all law enforcement personnel from the College Station Police Department that will have access to the traffic violation database should complete training on the capabilities and proper use of the system. A test system should be installed at one intersection and one highway-railroad grade crossing. One speed trailers will also need to be assembled and deployed in the field. This should be done to test the design and determine if the processing unit on-site will transfer the data into the database. The overall system should be checked rechecked and all necessary changes should be made. Full installation may then begin at all the specified locations. Thorough testing should then be completed on the entire system to ensure the detection equipment is functioning properly. The data transfer procedure should also be reevaluated.

The traffic violation database system should now be fully functional and gathering violation data to create a means by which the College Station Police Department may better monitor the city street system. It is important that the system be expanded when the resources are available. Expanding the system will assure the largest possible coverage area and increase deployment efficiency. The equipment should also be continually maintained to ensure the longevity of the program.

For illustrative purposes detection equipment will be applied to the intersection of Texas Avenue and Southwest Parkway. All approaches have two thru lanes and a left-turn bay. Two inductive loop detectors are placed in each lane on all four approaches. The downstream detector is placed with its upstream edge adjacent to the stopbar. The upstream detector is placed two meters from the downstream detector front to back on center. A speed of 10 mph will be used as the threshold above which the detection is considered a violation. By allowing a speed comparison vehicles that come to rest on the inductive loops or are making a turning movement will not be counted as a violation. The processing unit will be housed in the signal cabinet and allow for dial-up data downloading through a modem connection. The processing unit will also be wired into the signal controller to active the appropriate loops during their associated red phase. The violation detection configuration for Texas Avenue and Southwest Parkway is illustrated in Figure 5.

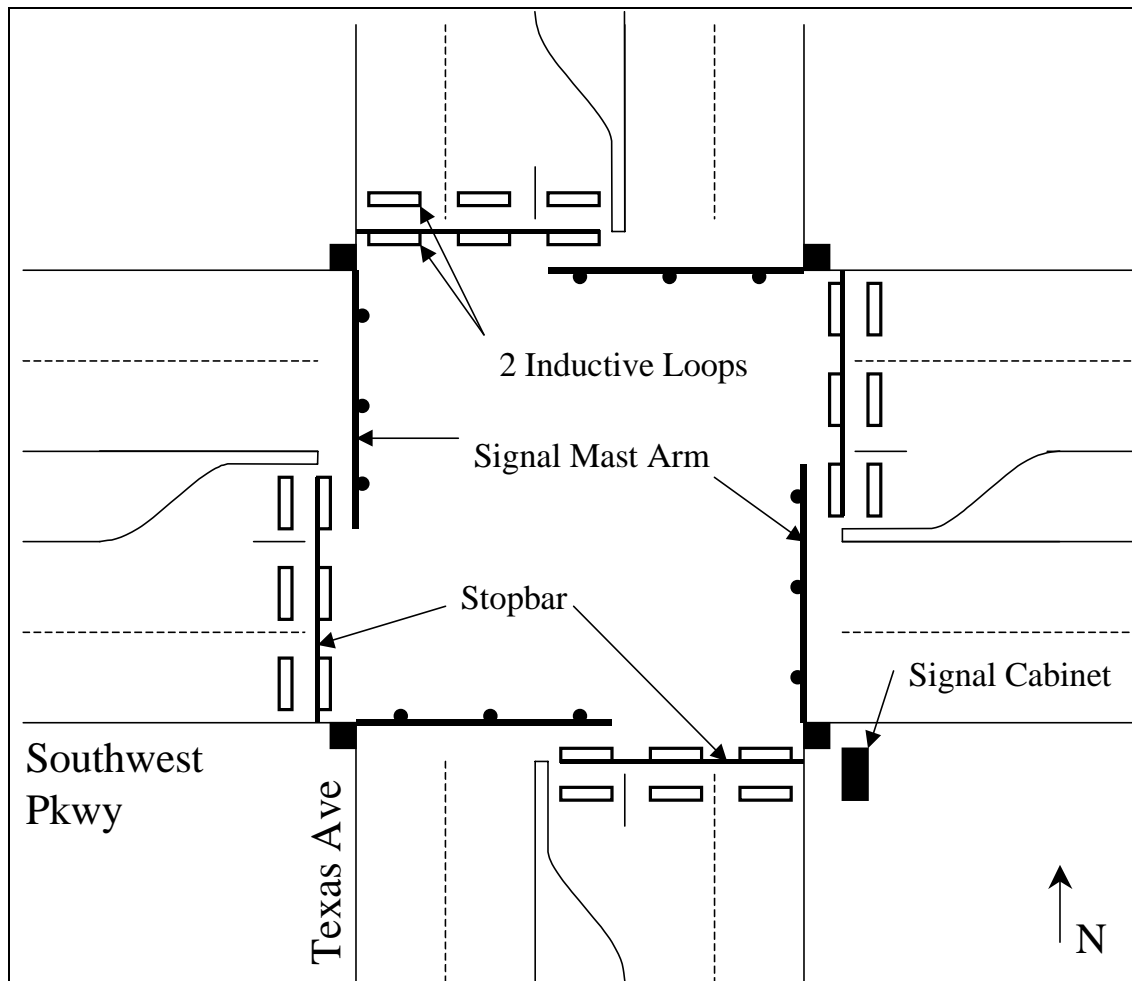


Figure 5. Vehicle Detection Equipment (Texas Avenue & Southwest Parkway)

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Appendix A - Law Enforcement Survey

As part of the Advanced Institute program at Texas A&M University, I am surveying law enforcement personnel to help determine the process and equipment needed to create a traffic violation database where automated enforcement equipment and other technologies are used to assist law enforcement in determining where their limited resources are most needed. This system would not be used to issue citations, record license plate numbers or identify drivers, but instead would be a way of monitoring driver behavior in critical parts of the city street system. Law enforcement personnel could access the traffic violation database and search by intersection or street for data relating to red-light running, highway-railroad grade crossing gate violations or speeding. Copies of this survey may be given to any law enforcement personnel interested in participating. Your time and comments are greatly appreciated and will be beneficial in determining the usefulness of such a system to law enforcement personnel. **Please fax all completed surveys to Randy Carroll at (409) 845-6481 by July 2, 1999.**

Please complete the following questions.

City: _____ State: _____
Agency: _____ Position: _____

1. Would this type of system address an existing need at your agency? Yes No If yes, what: _____

2. Would this type of system become a regular / integral part of your enforcement activities or just used in special situations?
 Regular / Integral Special Situations Why: _____

3. Would this type of system influence decisions on where to conduct enforcement activities? Yes No If yes, how: _____

4. Where would your agency experience benefits in enforcement efficiency and/or effectiveness from this type of system?
 Manpower In what ways: _____
 Time In what ways: _____
 Equipment In what ways: _____
 Other In what ways: _____

5. What computer programs and capabilities does your agency currently possess?
 DOS Based Programs.... Are you comfortable using this computer format? Yes No
 Windows Based Programs.... Are you comfortable using this computer format? Yes No
 Internet / Web Browser.... Are you comfortable using the Internet? Yes No

6. Typically, how do you establish an intersection, grade crossing, etc. as a problem location?
 Current violation rates Accident Rates Public Opinion Personal Observation
 Other: _____

7. How do you currently make decisions on where and when to deploy your resources? _____

8. How useful would you expect a system that could historically document traffic violations to be in educating the public or city officials on law enforcement concerns?

9. How much time per week would you be willing / able to spend manually entering information, that could not be automatically gathered, into the system?
 0 hrs 1 hrs 2 hrs 3 hrs 4 hrs 5 hrs 6 hrs More than 6 hrs

10. In terms of enforcing traffic laws and regulations, what information would you like to be able to easily access regarding a specific location or street?

Thank you, your responses are greatly appreciated. If you would be willing to discuss this issue further, please include your name and telephone number below.

Name: _____

Phone Number: _____

RANDY W. CARROLL

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**DETERMINING LOCAL TRAVEL TIME THRESHOLDS FOR USE IN
TRANSPORTATION DECISION-MAKING**

by

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CVEN 677

Advanced Surface Transportation Systems

Department of Civil Engineering

Texas A&M University

College Station, TX

August 1999

SUMMARY

Mobility is a complex component of level of service in transportation. There are many different measures which may be used to describe it, yet few of them are both understood by the public and capable of being used alone to describe a facility. Travel time has the potential to be a mobility measure that could satisfy both goals, yet it has not been used in the past because of data collection concerns.

In this paper, a methodology is presented for using travel time data to describe mobility. The method uses public perception data to help grade mobility based on the responses of surveyed travelers. In this way, the method links the level of service concept to a specific rating system.

An extensive literature review was conducted for this research, focusing on mobility, travel time, perception data, and preference models. The results of the literature review were supplemented by interviews with transportation professionals.

The result of this research is a method for using travel time data and public perception data together to determine level of service criteria for local decision-making. However, it is recommended that further research be conducted to determine more suitable ways of obtaining perception data.

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INTRODUCTION

Mobility is a complex, but very important, component of overall quality of service in traffic applications. It may be defined as “the ability to reach a destination in a time and cost that is satisfactory” (1). With the advent of Intelligent Transportation Systems (ITS), the potential to record and use data that measure mobility, such as travel time, is increasing. If this potential is realized, decision-makers will be able to use up-to-the-minute mobility data to make decisions about transportation projects. Moreover, the public is increasingly aware of and interested in transportation issues. Such interest is displayed in the demand for public meetings to discuss transportation improvements as well as the increased use of traffic information services. People are interested in not only the effects of large projects, but also the effects of daily congestion on the routes they use.

With this public interest, it becomes necessary for transportation professionals to be able to communicate effectively with the public and non-technical decision-makers. The terms used to describe the benefits of a project need to be terms that the public can understand, yet they also need to be complete in their description. Travel time is one mobility measure that may be suitable to describe a large number of transportation projects.

There is also a need to define thresholds for use of any measure in a decision-making process. Thresholds define the limits of acceptable service and help to prioritize projects. Ideally, thresholds should be based, to some degree, on the perception of local users, not on the consensus of government or even transportation officials. A transportation system, just like any other product, must serve the needs of its users, or it will not be used as intended. The focus of this research is to develop a method for determining travel time thresholds for use in transportation decision-making.

Objectives

There are two primary objectives of this research. They are to:

- Identify sources of public perception and travel time data, and
- Develop and recommend a method for determining travel time thresholds for use as a decision-making tool in the evaluation of local transportation system options.

The outcome of this research is a recommended source of these data and a recommended method for determining local travel time thresholds. This method allows local transportation agencies to calibrate and use a travel time-based model in decision-making that can be understood by the public and non-technical decision-makers. The method may also find future use as a component of overall quality of service in the Highway Capacity Manual.

Scope

The scope of this research is limited because of the short time allowed to complete the tasks. While investigations were made of the sources of travel time and user perception data, no attempt was made to actually obtain these data. Instead, the focus is on discovering the types of data that are available for use and creating a method that can use the available data.

Tasks

Four primary tasks were identified for this research. These tasks focused first on obtaining relevant information and then on using that information to develop the proposed method.

Literature Review

A state-of-the-art literature review was conducted, focusing on mobility measures, public comprehension of mobility, and factors that influence local acceptance of travel time. In this literature review, current research and methods in mobility measurement and public perception of traffic conditions were also identified. Finally, potential models for use in the development of travel time thresholds were found.

Interviews

In order to further the knowledge gained in the literature review, interviews were conducted of four transportation professionals interested in mobility measures and travel time data. In addition, these interviews were conducted in an attempt to discover the sources of travel time and public perception data for the models that were developed.

Identify Data Sources

As a result of the literature review and interviews, a summary was prepared of the sources of travel time and user perception data. In addition, recommendations were made regarding the most appropriate sources of this information.

Develop Models

Finally, models were developed for use in determining local travel time thresholds. Three different models were explored, and their relative advantages and disadvantages were discussed. Recommendations were made regarding the most appropriate model for use by local agencies.

Organization

This paper is organized in eight sections. In the first section, an introduction to the research is made. The second section contains a discussion of quality of service and mobility. In the third and fourth sections, a discussion of travel time and methods of collecting travel time data is presented. The content of the fifth and sixth sections is a discussion of perception data and the preference models that were investigated for this research. In the seventh section, the efforts in model development are documented, and the eighth section presents the recommendations and conclusions of this research.

QUALITY (OR LEVEL) OF SERVICE

Since the second version Highway Capacity Manual was written in 1965, quality (or level) of service has been the criterion for evaluating transportation decisions. Level of service was then defined as “a qualitative measure of the effect of a number of factors, which include speed and travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, and operating costs.” (2) As such, level of service is a rather broad term, encompassing the whole of travel conditions available on a particular route.

Quality of service has two main components. Mobility and accessibility, which are themselves very related terms, can be thought of as making up the two parts of quality of service. Mobility describes how easy the transportation system is to use, while accessibility describes how effectively the transportation system joins types of origins and destinations. Together, these two factors describe overall quality of service. Traditionally, however, only mobility measures have been used to estimate level of service.

Over the years, a number of different measures have been used to define quality of service. Practically, it is necessary to have one measure define level of service on a single facility. If more than one measure were

used to define a particular level of service, it would be possible for traffic conditions to be rated differently depending upon the measure. It would be desirable to use the same measure for all types of facilities, but this ideal measure has not yet been discovered and implemented. The measures that have been proposed are either not useful for all facilities or not easily estimated or observed.

Mobility

Mobility is a term that refers to the ease with which people and goods can move. Lomax and Schrank defined mobility as “the ability to reach a destination in a time and cost that is satisfactory.” (1) Mobility tends to describe the traffic conditions in the system at a given point in time and space. When travelers consider their transportation options, mobility affects such decisions as when to leave and which route to use. Mobility measures answer some of the immediate questions of a traveler. How fast is traffic moving? How long will the trip take? Is it better to leave early or late? Is there congestion? What is the best route to use? These questions all focus on the ease with which a traveler can move from one point to another in the transportation system.

The “satisfactory” part of mobility may vary depending on the time of day and location. Commuters going to work in a large city may find mild levels of congestion satisfactory. It would not, however, be satisfactory to find congestion on the same trip late at night. Likewise, travelers might find that speeds of 30-40 mph are acceptable on an urban collector but not on the freeway. Thus it is important that mobility measures be specific with regard to time and location of travel.

The opposite of mobility may be thought of as congestion (3). It is possible for a long trip to have high mobility if it is smooth and vehicles move at or near free speeds. However, a short trip may have low mobility if congestion and low speeds characterize it.

Accessibility

Accessibility is a term that refers to the ease with which desired activities can be reached from any and all locations. A more formal definition of accessibility is “the achievement of travel objectives within time limits regarded as acceptable.” (1) The concept of an acceptable time limit appears in the definitions for both mobility and accessibility, but accessibility refers more to the availability of activities. Accessibility affects transportation decisions such as where to go, what mode to use, and whether to travel at all.

Travelers are typically concerned with accessibility before they are concerned with mobility. Accessibility answers questions about where and how far away activities are. Where is the nearest convenience store? How long will it take to get to work from this neighborhood? Is there a school nearby? These questions focus on the relationship between the place of origin and the location of the desired type of activity. An activity (shopping, working, dining out) is said to be accessible to a location if it can be typically reached within an acceptable time limit. These time limits vary depending on the nature of the activity.

Typically, accessibility is more difficult to measure than mobility. Land use and travel time measures seem to capture accessibility concerns most completely. Accessibility is more easily addressed on a large geographic scale, such as a corridor or a region. Therefore, it does not capture the effects of points in the system except as they in turn affect the larger geographic scope.

Measuring Quality of Service

Many different measures could be (and have been) used to define quality of service. Since 1965, the Highway Capacity Manual has used eight different measures to delineate level of service thresholds (2, 4, 5, 6). Others have been proposed that have not been included in the Highway Capacity Manual. Most (if

not all) of these measures are mobility measures. The following subsections describe some of these measures.

Volume to Capacity (v/c) Ratio

The volume to capacity ratio was one of the first level of service criteria adopted in the Highway Capacity Manual (2). Estimates of capacity are made by either observing a facility or comparing the facility with others like it. Similarly, the demand volume on the facility is estimated based on field observations or planning models. Low v/c ratios are indicative of freely flowing traffic, while high v/c ratios reflect congested conditions.

The v/c ratio has fallen out of favor with analysts for two reasons. First, it does not directly relate to the driving experience. As a result, the general public has a hard time understanding the terms that are used as inputs to the measure. Second, the misuse of terms has caused confusion among analysts. The difference between demand and actual volume is a subtle concern that is often misinterpreted, with critical results.

Load Factor

In the 1965 Highway Capacity Manual, the load factor was used to evaluate signalized intersections. It is defined as “the ratio of the total number of green signal intervals that are fully utilized by traffic during the peak hour to the total number of green intervals for that approach during the same period” (2). Besides being difficult to calculate and understand, data collection for the load factor was difficult. Estimating the load factor for proposed intersections required the use of a number of nomographs provided in the Manual. The next version replaced load factor with delay (4).

The term load factor changed meanings in the 1985 Highway Capacity Manual. It was now used for analysis of public transit, and referred to the ratio of the number of people on the vehicle to the number of seats provided. Other factors are also used to describe transit level of service, such as the flow rate of transit vehicles in dedicated lanes. Transit level of service is especially difficult to estimate because it is comprised of two components: passenger comfort and traffic conditions. The two measures employed by the Highway Capacity Manual attempt to capture both sides of transit operations (4).

Flow Rate

Flow rate has been used since the 1965 Highway Capacity Manual to assign level of service to ramp junctions (2). Ramp junctions are the only facility to use this measure, primarily because so many factors contribute to their operations. At a ramp junction, a level of service value is assigned to both the ramp and the freeway based on the flow rates on each. The lowest (worst) of those levels of service is assumed to govern and is assigned to the junction.

Ramp junctions are difficult to understand because they are complex. The wide range of geometric considerations requires a large number of equations and/or nomographs for their analysis. In addition, the behavior of drivers at junctions is not fully understood, preventing more complex or detailed analyses.

Speed

Travel speed is the last level of service criteria used in the 1965 Highway Capacity Manual (2). It has survived four decades of use and is still used to determine level of service on arterial segments and uninterrupted facilities (6).

Speed is an advantageous measure because it is applicable at a number of points. Time mean speeds can be used to assess the quality of service on an uninterrupted facility while space mean speeds can be used to evaluate interrupted facilities. Speed is also a concept that is readily understood by motorists.

However, speed can also be a difficult measure with which to work. The difference between space mean and time mean speed is a very important and subtle one that the general public (and traffic analysts, in some cases!) does not understand. In addition, extensive tables must be constructed to define level of service thresholds for various facility types. Finally, the use of speed as a level of service criteria might tempt some planners to increase speed limits to improve service. In so doing, safety may be jeopardized, and the source of the service problem is not properly addressed.

Density

In 1985, the Highway Capacity Manual began to use density to assign levels of service to freeways and multi-lane highways (4). In 1997, weaving sections were also evaluated using density (6). Density was chosen for these analyses of uninterrupted facilities because it is a measure that relates to the driver's freedom to maneuver and proximity to other vehicles (4). Density has an advantage over speed (which used to be the primary measure for these facilities) in that it does not need to be recalibrated for every speed limit.

Unfortunately, density is another term that is not understood by the general public. While drivers may have some sense of density's inverse (space headway), they have little feel for density itself. Density is also not applicable to interrupted facilities, as the measured value changes based on the operations of the opposing traffic stream or the indications of a traffic signal. Finally, density is a difficult quantity to measure directly. Loop detectors, which are most commonly used for these measurements, cannot be used to measure density directly, but instead are used to measure occupancy, which must be converted to density based on assumptions about traffic composition.

An alternative to using inductive loops to measure density is aerial photography. A Maryland-based firm specializes in using photographs captured while flying over a city to estimate level of service on both freeways and arterials. Density is directly measured in an aerial photograph, although the measure is computed only for the time of the photograph (7).

Reserve Capacity

Reserve capacity was used in the 1985 Highway Capacity Manual to assign level of service to unsignalized intersections. Reserve capacity is the unused capacity of a lane approaching a stop sign. It seems to have been an interim measure used while theories on how to estimate stopped or control delay at unsignalized intersections were being developed and accepted. Strong language was included in the Manual warning analysts that the levels of service used for unsignalized intersections were not to be associated with the delay values used to analyze signalized intersections. In the 1994 revision, average total delay replaced reserve capacity (5).

Percent Time Delay

Percent time delay is used to analyze two-lane highways. This measure reflects the unique condition of these highways whereby a faster vehicle can experience delay when it is forced to follow a slower vehicle because passing sight distance is not adequate. It also incorporates to some degree the effects of extended grades along the highway (4).

In practice, the percent time delay is never actually calculated. The defined threshold values are used to help define peak-hour volumes that form the thresholds for the various levels of service. These volumes are calculated specifically for each highway and compared with the actual volume observed or estimated.

Delay

Delay is most often used for estimating level of service at both signalized and unsignalized intersections. The public easily understands delay, although many drivers' perception of delay is much greater than that actually experienced at an intersection. Delay has been adopted by the Highway Capacity Manual for use with signalized intersections in 1985 and unsignalized intersections in 1994 (4, 6).

Three forms of delay have been proposed to analyze intersections. Stopped delay refers to delay experienced while a vehicle is actually stopped at an intersection. Control delay includes stopped delay, but also takes note of the extra delay caused by the need to slow down and start up again. Total delay includes control delay and any additional delay caused by geometric conditions (i.e., curb radii, length and width of the intersection, etc.) at the intersection. All three measures can be measured in the field or estimated based on projected conditions. Currently, the Highway Capacity Manual uses control delay for all intersections (6).

Travel Time

Travel time, like delay, is a measure that is easily understood by the general public. It can be measured based on field observations or estimated based on projected conditions. However, the Highway Capacity Manual has never formally adopted it for use in establishing levels of service. One reason that it has never been adopted is that, until recently, travel time data was not cost-effective to measure in the field. Measurement was possible, through means such as probe vehicles or license plate surveys, but such studies were expensive and had to be customized to facility for which travel time data were requested. Another reason is that if levels of service were to be determined based on travel time, they would have to be customized for the facility. No procedures exist (other than those presented in this paper) to develop levels of service on an individual facility based upon travel time.

However, with the advent of Intelligent Transportation Systems (ITS), travel time is becoming a more easily measured quantity. Vehicle tracking systems such as Automatic Vehicle Identification (AVI) and Automatic Vehicle Location (AVL) have created a virtual flood of travel time information. Also, many of the other sensors being placed in the field for other purposes (such as loop detectors and video cameras) have the potential to estimate travel time in addition to their intended purpose.

TRAVEL TIME

Travel time is a characteristic of traffic conditions that is readily understood by the general public. It is also a measure that can be applied to a wide variety of facilities. Travel time data are also beginning to be collected in large quantities in large urban areas. With these characteristics, it is conceivable that travel time could be used to establish level of service criteria.

Lomax and Schrank identified nine characteristics of an ideal mobility measure (1). These characteristics, if satisfied, will produce a measure that can be used with confidence to analyze transportation facilities. Travel time has the potential to satisfy many of these characteristics. In the discussion that follows, these characteristics are described. In addition, travel time is compared to the demands of each to evaluate its performance as a mobility measure.

Related to Goals and Objectives

An ideal mobility measure will help further the goals and objectives of a comprehensive transportation program. It will measure progress toward those goals and also identify areas that have not yet reached their goal. It should also be able to be continually monitored so that the fulfillment of these objectives can be documented (1).

Travel time is a measure that is clearly related to many transportation goals and objectives. Low travel times are generally indicative of an efficient system and high travel times identify areas where either mobility or accessibility is impeded. The use of ITS-related monitoring systems will allow municipalities to continually measure travel time as travel conditions change. In addition, the automated systems are relatively low-cost as compared to using technicians to gather the same amount of data.

Travel time may not be a good indicator of some transportation goals, however. Safety and comfort are not easily measured by travel time. In fact, the use of travel time alone may result in changes to higher speed limits, which would be detrimental to both goals.

Clearly Communicate Results to Audiences

The need for an easily understood mobility measure has already been presented. Analysts and engineers are not the only people who need to understand the chosen measure or how to apply it. Decision-makers and the general public, many of whom do not have an extensive technical background also need to understand these measures. This qualification does not relate to the difficulty of calculating the measure, only the ease of understanding it when it is presented (*L*).

Travel time is an easily understood measure, because it relates directly to the driving task. When travelers make a decision about transportation, travel time is nearly always a factor. Travel time communicates to travelers information about the distance of a trip and traffic conditions along the chosen route. Depending on the expected travel time, the traveler may choose to change modes, change routes, leave early, leave late, or even to cancel the trip.

Include Urban Travel Modes

An ideal mobility measure is one that can be computed for any of the various alternative modes available to a traveler. It should not favor one mode over another by incorporating a bias. It should also be equally representative of each alternative mode (*L*).

Travel time is a measure that can be computed for every transportation mode. However, it may not completely describe the quality of the trip, particularly transit trips. Travel time cannot capture information about how crowded a bus or subway is; yet, these factors contribute to the overall quality of service.

Consistency and Accuracy

The need for consistency exists on several levels. Similar levels of mobility should have similar mobility measures. This thought has been the basis for converting mobility measures into a graded scale. Ideally, each level of service grade would be perceived to result in similar levels of mobility, regardless of the type of facility. Consistency also relates to precision; a consistent measure should produce similar value when it is used to measure similar conditions (*L*).

A consistent measure is of no use unless it is also accurate. Analysts have expounded the need for accuracy for a long time. In order to achieve a given level of accuracy, a corresponding level of complexity is needed in the method. It is important to identify that level of complexity, and it is equally important that this level remain constant.

Travel time is a measure that can be either directly observed with great accuracy or estimated with little loss. When it is estimated, bounds can usually be developed for the estimate. Direct point-to-point travel time is a consistent measure primarily because it is easily interpreted and validated.

Illustrate Effect of Improvements

Regardless of the scope of the improvement, the ideal mobility measure should be able to demonstrate the effectiveness of the improvement. It is important that the scope of the measure match the scope of the improvement (*L*).

For many planning or operations improvements, travel time can be used to demonstrate the effectiveness of the improvement. Changes in travel time can show the effects of retiming a traffic signal as well as the effects of adding another lane to an existing roadway. It can also be used to evaluate operations improvements in transit operations as well as other traffic.

Applicable to Existing and Future Conditions

The ideal mobility measure is one that can be estimated as well as observed. This quality makes the measure useful for analysis and planning. The existence of empirical or theoretical means of estimating the measure is also indicative of careful study and understanding (*L*).

Travel time is already being both observed and estimated in transportation systems. The Travel Time Data Collection Handbook describes a number of ways in which travel time data can be observed in the field (*8*). Theoretical models, such as Webster's delay equations, also result in travel time estimates. Travel time can also be estimated by simple means using only speed limits and distances.

Applicable at Several Geographic Levels

An effective mobility measure can be applied with equal precision and credibility at a variety of geographic levels. This quality makes it useful for analyzing points in the system, such as intersections, or wide areas, such as corridors. It also allows the measure to be used for both macroscopic and microscopic analyses (*L*).

Travel time is a quantity that can be measured or estimated almost anywhere in a transportation system. As long as there is a non-zero distance between two points, the travel time between them can be found. Even at intersections, which are considered to be points in the system, travel time can be found in terms of average delay. Travel time is also a measure that can be computed microscopically (for individual vehicles) or macroscopically (for a platoon).

Use Person and Goods Movement Terms

Ideally, a mobility measure will describe travel conditions in terms of people and goods. System efficiency is best documented in these terms, describing how well or how often the system is used. They also give some idea of the scope of problems. When problems happen to large numbers of people or goods, the problem is considered more important. An ideal mobility measure will use terms that help to quantify the magnitude of concern (*L*).

Travel time cannot measure system throughput, such as persons or tons of freight moved. Some travel time-based measures, such as time per person or time per ton, may show some improvement in efficiency, but they do not capture this goal as well as volume measures do.

Use Cost Effective Methods to Collect and/or Estimate Data

Finally, an ideal mobility measure should not be difficult or expensive to measure. This concern is always present when budgets are limited. If the data are already available or inexpensive to collect, more can be

done with it. An efficient allocation of resources requires the use of cost effective data collection methods (L).

In the past, travel time data were relatively difficult to collect. It required a large amount of human labor, which was expensive. New ITS technologies, however, have significantly reduced the amount of data collection effort required. Much of this data collection can be performed by a computer, without ever needing a human operator's input until the final data are requested (8).

OBTAINING TRAVEL TIME DATA

The Federal Highway Administration (FHWA), in cooperation with the Texas Transportation Institute, created a document called the Travel Time Data Collection Handbook. In the publication, many of the most popular and cost-effective methods used for collecting travel time data are reviewed (8).

Travel time is generally composed of two components. Running time is the time the vehicle spends in motion. Stopped delay time is the time the vehicle spends stopped, or moving sufficiently slow as to be stopped (usually less than 5 mph). This concept is illustrated in Figure 1.

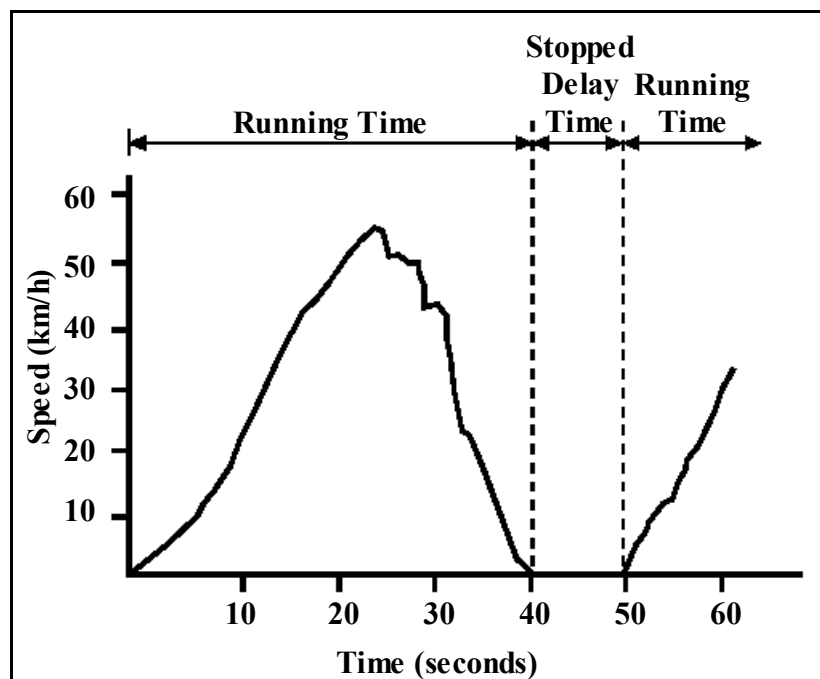


Figure 1. Illustration of Running and Stopped Delay Time (8).

Travel time can also be estimated by assuming that a spot speed observed at a particular point is constant over a short distance (usually 0.5 miles or less). This assumption is most applicable to uninterrupted facilities (8).

Several methods for measuring travel time are described in the Handbook. In the following sections, a brief review of each of these methods is presented.

Test Vehicle

The test vehicle technique is the oldest and most commonly used method for obtaining travel time information. A test vehicle is driven along a specified route and travel times are recorded at checkpoints along the path. For this reason, this technique is sometimes called the “active probe” technique. The travel times may be recorded in one of three different ways: manually, using an electronic distance measuring instrument (DMI), or using global positioning system (GPS) information (8).

Manual data collection requires a passenger to accompany the driver on the trip. As the driver passes the checkpoints, the passenger records the travel time information. Electronic DMIs have automated this process, using a computer that receives information from the transmission of the vehicle. The transmission sends pulses of information to the computer that allow it to compute the speed and distance elapsed since the last pulse was sent. The GPS method further automates the process by using signals from Department of Defense satellites to determine the position of the test vehicle. The test vehicle is equipped with a GPS transmitter and the laboratory computer is equipped with a GPS receiver. One computer can track an entire fleet of test vehicles using the GPS method (8).

In the test vehicle technique, the driver is an important part of the data collection process. The aggressiveness of the driver can have a great impact on the results of the data collection effort. Therefore, three different driving methods have been developed to control variation among drivers.

- Average car: the driver drives according to his/her judgement of an average car in the vehicle stream.
- Floating car: the test vehicle “floats” in traffic by attempting to safely pass as many vehicles as pass the test vehicle.
- Maximum car: the driver attempts to drive at the speed limit as much as possible unless impeded by other vehicles or traffic conditions (8).

In practice, some combination of the average car and floating car methods are used because of the difficulty of keeping track of the number of cars passed.

The advantages of the test vehicle technique include:

- Provides for the determination of driving styles (e.g., “floating car”), which provides consistent data collection;
- Advanced test vehicle techniques (e.g., DMI or GPS use) result in detailed data that cover the entire study corridor; and
- Relatively low initial cost.

The disadvantages of the test vehicle technique include:

- Sources of possible error from either human or electric sources that require adequate quality control;
- Advanced and detailed data collection techniques (e.g., every second) can provide data storage difficulties; and
- The travel time estimates for the corridor are based on only one vehicle that is in the traffic stream, traveling at one specific time.

By making provisions for quality control, adequate data storage, and a large sample size, the test vehicle technique can provide an accurate estimate of travel time in a corridor. However, it is often difficult to obtain the large sample size that is statistically necessary due to budgetary constraints. Other techniques must be employed if a large sample is needed.

License Plate Matching

License plate matching is a data collection method that is capable of recording a large number of travel times between observation points. License plate numbers and observation times are recorded at each of the observation stations. When vehicles are observed at more than one station, they are assumed to have traveled between the two posts without stopping and the time between consecutive observations is recorded as their travel time. The basic principle of the method is illustrated in Figure 2 (8).

There are several different methods used to record license plate matching data. The manual method uses human observers to record license plates and the times they were observed. The portable computer method automates the time stamp process by using a portable computer to keep track of when each vehicle was observed. The video with manual transcription technique uses video cameras to record traffic at each site and human technicians record the license plate numbers and observation times in the office. The video with character recognition technique uses advanced computer imaging to automatically record license plate numbers as they are recorded on video (8).

License plate matching has several advantages:

- Able to obtain travel times from a large sample of motorists, which is useful in understanding variability of travel times among vehicles within the traffic stream;
- Provides a continuum of travel times during the data collection period and ability to analyze short time periods (e.g., 15-minute averages for continuous data); and
- Data collection equipment relatively portable between observation sites.

License plate matching also has several disadvantages:

- Travel time data limited to locations where observers or video cameras can be positioned;
- Limited geographic coverage on a single day;
- Manual and portable computer-based methods are less practical for high-speed freeways or long sections of roadway with a low percentage of through-traffic;
- Accuracy of license plate reading is an issue for manual and portable computer-based methods; and
- Skilled data collection personnel required for collecting license plates and/or operating electronic equipment.

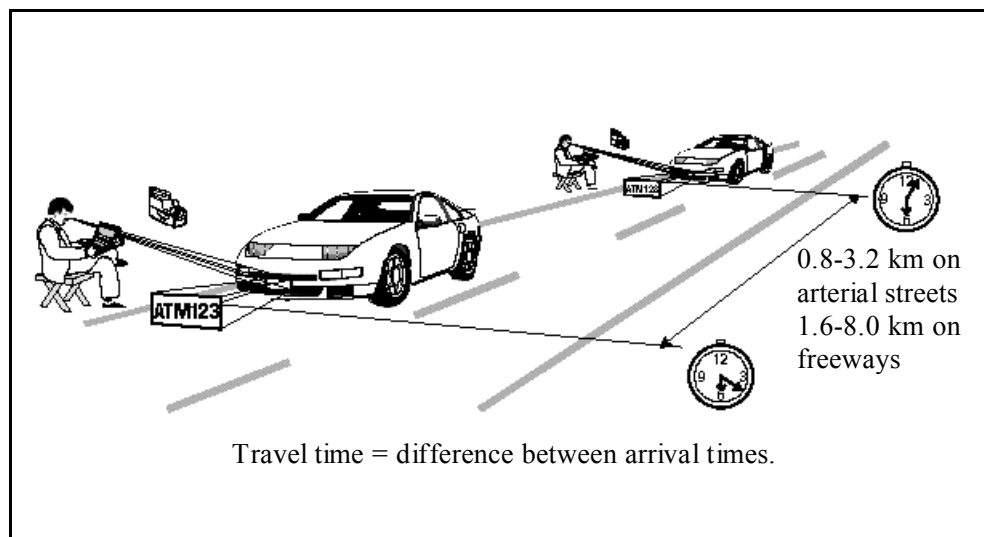


Figure 2. License Plate Matching Technique (8).

License plate matching is an effective means of capturing many point-to-point travel times. However, it is limited by the amount of equipment and personnel available for data collection.

ITS Probe Data

Another method for using probe vehicles is to use ITS means for obtaining the data. This method is sometimes called the “passive probe” technique, in contrast to the “active probe” technique presented earlier (8).

There are a number of means of obtaining ITS travel time data from vehicles, depending upon the extent of ITS implementation in an area. Five such means were presented in the Travel Time Data Collection Handbook: Signpost-Based Automatic Vehicle Location (AVL), Automatic Vehicle Identification (AVI), Ground-Based Radio Navigation, Cellular Geo-location, and Global Positioning System (GPS). Each of these technologies rely on devices placed inside the vehicle that allow external tracking systems to monitor the locations of these ITS probes. An example of an AVI system is shown in Figure 3 (8).

The advantages of ITS techniques are:

- Once the necessary infrastructure and equipment are in place, data may be collected easily and at low cost;
- Travel time data may be collected 24 hours per day with ITS probe vehicle systems. If the infrastructure is permanently installed, data are collected as long as probe vehicles continue to travel through the system;
- Data can be collected electronically; and
- Since data are collected from probes within the traffic stream, the traffic is not influenced by the experimenter.

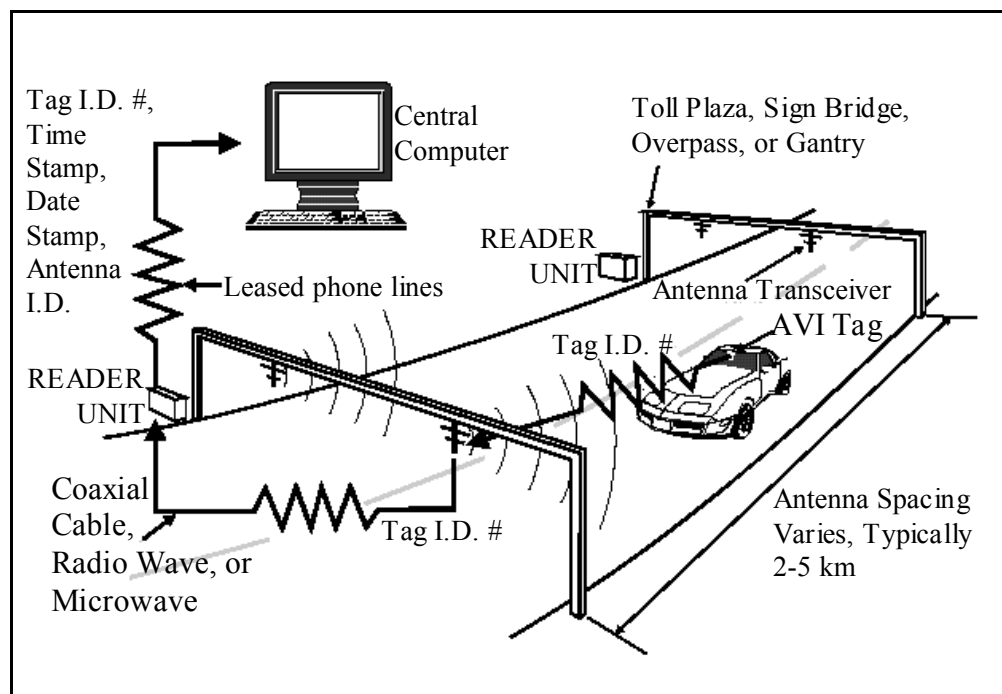


Figure 3. AVI System (8).

The disadvantages of ITS techniques are:

- Probe vehicle systems typically have a high initial cost to purchase necessary equipment, install the equipment, and train personnel to operate the system and collect data;
- Once the fixed infrastructure of receiving antennas is implemented, it is generally not financially feasible to make adjustments in the size and orientation of the system coverage area (GPS is the exception);
- The software that performs the data collection tasks are complex programs and are typically designed in-house or by a consultant;
- Motorists are concerned that if they have a probe they may be more likely to receive traffic citations or have their travel habits monitored; and
- Probe vehicle systems generally have large implementation costs, and they are most cost-effective for collecting data within a large study area.

A large, permanent, continuous data collection effort can most effectively be made using ITS techniques. The high cost of infrastructure improvements makes them unsuitable for single-application uses. In addition, the high cost requires a commitment to operate and maintain these devices.

Non-Traditional Methods

There are other non-traditional or experimental methods that are used to collect travel time data. Several of these methods focus on using point vehicle detection equipment (such as loop detectors and cameras) to either track vehicles or estimate speeds at a location. These techniques are not commonly used in data collection efforts.

Extrapolation Method

The extrapolation method uses observed point speed measurements to approximate travel time through a corridor. It is generally assumed that in the vicinity of the observation, speeds are constant. This assumption allows the use of simple algorithms for the calculation of travel times between detector stations. The most commonly used instruments are loop detectors and cameras (8).

The advantage of these methods is that they use equipment that is already in place. Loop detectors and cameras have already been installed in many cities and are used for volume counts and other data collection purposes. By using existing equipment, the implementation costs are reduced. The disadvantage is that these methods only estimate travel time between stations. The assumption of constant speed in the vicinity of the detector may be invalid, particularly during peak periods. If detectors are not sufficiently close to one another, this may increase the error.

Vehicle Signature Matching

The vehicle signature matching techniques use cameras, loop detectors, weigh-in-motion detectors, or some other means to identify a vehicle as it passes a detection station. If the same signature is identified at a downstream detector, it is assumed that the vehicle traveled between the two stations without stopping (8).

This method is able to either use equipment that is already installed in the field, or equipment that can be easily installed. It has the advantage over extrapolation techniques that it measures real travel times instead of estimating them. However, signatures may be confused so that not every vehicle that travels between the two points is correctly matched. Even worse, individual vehicles may be matched with another similar vehicle resulting in a false travel time.

Platoon Matching

Platoon matching techniques use point sensors to observe platoons of vehicles as they travel along an arterial. The identifiable characteristics of the platoon (position and spacing of headways, for example) are recorded and matched to those of the same platoon as it is recorded downstream (8).

Platoon matching offers the same benefits as vehicle signature matching. However, it is susceptible to the same types of concerns, particularly that when a platoon reaches the downstream sensor it may not be recognizable. If there are many driveways between detectors or if the detector spacing is too large, the platoon may break apart before it reaches the downstream sensor.

Aerial Surveys

Aerial surveys typically use fixed-wing aircraft to photograph a particular study area. Although fixed-wing aircraft are most often used, other aircraft such as balloons, satellites, and remote-controlled gliders have been proposed. An alternative to photographing an entire area is tracking particular vehicles as they travel through the network. Most of these methods are only experimental – they have yet to be used and validated (7, 8).

Aerial surveys have the advantage that they can cover a wide geographic area in a single flight. However, photographs can only record vehicle density on a highway, which must be converted to vehicle speeds before they can be used to estimate travel time. Aerial vehicle tracking has potential as a travel time data collection method, but it has never been tested.

OBTAINING PUBLIC PERCEPTION DATA

Public perception data is not very common in transportation applications. Transportation planners use preference data to make choices about future growth, but they rarely ask the public to rate transportation projects. Interviews with several transportation professionals revealed no sources of data on real-time public perception of traffic conditions, although most thought it would be useful (9- 12).

If mobility criteria are to be graded in a fashion similar to that used in the Highway Capacity Manual, it is beneficial to use perception data to help develop the boundary thresholds between grades. Perception data helps analysts understand how an individual makes a choice. This type of data can also be used to develop threshold boundaries for grading level of service on individual transportation facilities. The use of perception data will help planners maintain an equal perception of level of service across many different facility types in many locations.

The most likely method to be implemented for obtaining these data is some type of survey. Surveys have been used for planning purposes for many years. Household surveys are very common for estimating origin-destination patterns. Travel diaries have also been used for these purposes (13).

Obtaining real-time perception data is a unique and necessary challenge if perception data are to be used to grade mobility. The literature and interviews revealed no methods of obtaining such data. However, the author submits that it may be possible to collect these data in conjunction with some of the ITS travel time data collection methods.

The ITS travel time data collection methods automate the process of collecting travel times of individual vehicles. In most cases, these methods require probe vehicles to be equipped with transponders of some fashion. This transponder technology could be used to transmit not only the position of a probe vehicle but also the driver's level of satisfaction with traffic conditions. A push-button device could be installed in the

vehicle to allow the driver to communicate his perception of current traffic conditions to analysts. Alternatively, subject drivers could be asked to use cellular phones to inform analysts when conditions reach an unacceptable level. Motorist safety is a concern for both of these methods, however. This area of data collection has yet to be explored to its full potential, and further research is required to appreciate the contributions of perception data.

When data collection plans are made, there is a need to decide what type of data is requested. Perception data is generally in one of two forms: acceptable/non-acceptable or rating schemes.

Acceptable/Non-Acceptable

If survey responders are asked to rate the system based on whether they feel that their experiences are acceptable, the data that are collected are binary in nature. There are only two possible responses: acceptable or non-acceptable.

Using this type of data tends to simplify the problem of data analysis. Less complex methods may be employed to find the threshold between acceptable and non-acceptable conditions.

Binary data also allows transportation planners to identify areas of primary concern. If a significant proportion of users find a particular route unacceptable, the route could then be identified as a problem area. If a route is identified as being unacceptable during unusual congestion (such as that during an incident or construction), the threshold values obtained may be used to help monitor that route. When conditions worsen so that they are below the threshold, the area should be submitted as a candidate for improvement.

Rating Schemes

The second option available for data collection is that of a rating or grading scheme. This option is similar to the level of service grades that are currently used in the Highway Capacity Manual. Individuals would be asked to rate their experiences on a scale, reporting in real time when their perception of traffic conditions changes.

Rating schemes are more difficult to analyze, as they require potentially more complex data analysis techniques. Depending on the model chosen for use, a closed-form solution may not exist. However, a rating scheme offers advantages over binary data. First, drivers are able to identify similar levels of service at different facilities. Use of this type of data would allow the construction of a rating scale that can truly be compared across facilities. Second, there is more detail in this type of rating. By identifying boundaries between several levels of service, analysts can monitor the degradation or improvement of conditions at a particular facility.

When using a rating scheme to evaluate travel time data, it is important to pick the allowable responses carefully. An intuitive approach would be to allow individuals to rate the system on a scale such as “A” to “F”, or 1 - 10. However, if travel times become so short that they are perceived as dangerous or uncomfortable, a fast travel time might receive the same rating as a slow travel time. In order to avoid confusion, the rating scheme should be chosen so as to allow the individual to distinguish between travel times that are both so fast and so slow as to be uncomfortable.

A good rating scheme would be presented as follows:

	Too Fast	Fast	Acceptable	Slow	Too Slow
Please rate the travel conditions you experienced	1	2	3	4	5

This scheme would allow the surveyed individual to place upper and lower boundaries on safe and comfortable travel times, as well as give an indication of the level of service on a facility. In order to understand the range of travel times encompassed by a particular level of service, it would be necessary to obtain ratings for a number of different observed travel times.

PREFERENCE MODELS

A number of different choice or preference models are used in transportation planning. Among these are the maximum likelihood estimate (used for critical gap estimation), the logit, and the probit models. In their basic form, each of these models is a binary choice model: that is, they model the choice between two mutually exclusive options. The logit and probit models can be modified to include a number of different choices.

In this chapter, the three models mentioned above are described. A short background in utility theory, which is necessary to understand the logit and probit models, is also given. Finally, a discussion of the similarities and difference between perception and preference data illustrates the applicability of these models to perception data.

Random Utility Theory

In order to use most of the models presented below, the utility of each choice available to the user needs to be calculated. Utility is a mathematical construct devised for finding the solution to a preference problem, and is defined as the quantity the user seeks to maximize. Utility is usually thought of as being the personal benefit derived from the attributes of a particular choice. Positive attributes contribute positive utility while negative attributes contribute negative utility (13).

There are four postulates in random utility theory. These postulates describe the inherent properties of both the decision-maker and the options among which he must choose.

Homogeneous Population

Individuals belong to a homogeneous population, act rationally, and have perfect information about their choices. In other words, individuals always select the option that maximizes their individual net utility, subject to legal, social, physical, and/or budgetary constraints (13).

Limited Alternatives

Individuals are able to select from a predetermined, limited set of alternatives. There is a particular set $\mathbf{A} = \{A_1, \dots, A_j, \dots, A_N\}$ of available options from which the individual must choose. In addition, there exists a set \mathbf{X} of measured attributes of individuals and their alternatives. An individual q with a set of attributes $\mathbf{x} \in \mathbf{X}$ must choose among a set of alternatives $\mathbf{A}(q) \in \mathbf{A}$. The set of alternatives available to each individual is based upon the constraints identified in the first postulate (13).

Utility of an Option

Each option $A_j \in \mathbf{A}$ available to an individual has a unique utility U_{jq} for user q . The modeler, because he is necessarily outside of the individual's decision-making process, does not possess perfect knowledge of all the factors that contribute to the individual's choice. Therefore, the utility of an option is thought of as having two distinct components:

- A measurable, systematic, or representative part V_j which is a function of the measured attributes \mathbf{x} ; and
- A random part ε_{jq} that explains the variation not captured by the measured attributes. This random part represents the tastes and biases of the user and explains why two individuals with the same choices and the same measured attributes may make different decisions. It also explains why some users may not select the “best” alternative given the limited set of attributes considered by the modeler (13).

Therefore, the specific utility of an option A_j to a user q can be written:

$$U_{jq} = V_{jq} + \varepsilon_{jq} \quad \text{Eq. 1}$$

Maximum Utility Choice

It is assumed that each individual will choose the option that maximizes his/her individual utility. That is, when presented with choices \mathbf{A} , the individual will choose option A_j if and only if:

$$U_{jq} \leq U_{iq}, \forall A_i \in A(q) \quad \text{Eq. 2}$$

When dealing with perception data such as that presented earlier in this paper, the overall meaning of these assumptions is that a surveyed individual will pick the response that most suits his experience. For example, if a rating of “B” best describes travel conditions to that person, he will pick “B,” not “A” or “C,” if polled. The individual will not pick a rating that is not given to him (say “G” if the scale was from “A” to “F”). Finally, two individuals that have the same travel time experience may give different ratings based on other criteria. These different ratings show up in models as a random departure from the average (13).

Utility theory has no use outside of choice models that can use utility as an input. Two of the models described below, the logit and probit models, can use utility inputs. The other model, the maximum likelihood estimate, uses direct observations from individuals without converting them to utility.

Maximum Likelihood Estimate

The maximum likelihood model is the most respected model for estimating critical gaps. Critical gap theory is based on the assumption that when a driver seeks to enter or cross a traffic stream, he seeks a gap that is equal to or greater than some minimum size. If the gap is larger than the minimum, it is accepted. The choice in this situation is whether or not to accept a gap, based on its size (14).

The model is based on the assumption that there is a distribution of critical gaps consistent with a distribution of drivers. Within the population of drivers, there is a certain amount of randomness that is accounted for as the aggressiveness of the driver. Because aggressiveness is not a quantifiable variable, it is measured as a deviation from the mean critical gap of the population as a whole (14).

Another fundamental concept inherent in the maximum likelihood technique is that a driver’s critical gap is not directly observed. All that can be observed is whether or not a gap of a particular size was accepted. The critical gap should represent the boundary between accepted and rejected gaps. In practice, the largest rejected gap is compared with the gap the driver accepted. If no gaps are rejected (i.e., the driver accepted the first gap, or lag, presented), then the data for that driver are omitted (14).

The means of obtaining the maximum likelihood estimate of a critical gap begins with two variables describing one driver d :

r_d = largest rejected gap; and
 a_d = accepted gap.

The objective of the maximum likelihood method is to calculate the probability that the critical gap t_c is between the largest rejected and the accepted gap. The modeler must specify a general form of the distribution of critical gaps $f_c(t)$ among drivers in the population. The likelihood that a driver's critical gap will be between r_d and a_d is given by $f_a(a_d) - f_r(r_d)$. The likelihood L^* within a sample of n drivers for which a largest rejected and an accepted gap have been observed is:

$$L^* = \prod_{d=1}^n (f_a(a_d) - f_r(r_d)) \quad \text{Eq. 3}$$

The logarithm L of the likelihood L^* is given by:

$$L = \sum_{d=1}^n \ln(f_a(a_d) - f_r(r_d)) \quad \text{Eq. 4}$$

When L is maximized, so is L^* . The values of the parameters describing the critical gap (the mean and variance) are found by differentiating L with respect to each parameter and setting the partial derivative equal to zero. Two equations result, the solution of which is found through iterative numerical methods (14).

As a level of service model, the maximum likelihood estimate could be used to estimate the threshold between acceptable and unacceptable conditions. A suitable number of travelers could be observed to travel the same route a number of times during a specified time interval (i.e., the morning peak period). The travel conditions for each trip would be rated by each individual as acceptable or unacceptable. Then, for each driver, the largest acceptable travel time, a_d , and the smallest unacceptable travel time, r_d , can be observed. These terms replace the a_d and r_d terms in the discussion above, and the result of Equation 4 is the threshold between acceptable and unacceptable conditions during that travel period.

Logit

Logit choice models have received extensive use in the estimation of modal split. It is the simplest and most practical discrete choice model, generated by assuming that the random variable ϵ described earlier is a set of independent and identically distributed (IID) residuals following a Gumbel distribution. If this assumption is true, the probability of an individual making a particular choice is:

$$P_{iq} = \frac{\exp(V_{iq})}{\sum_{A_j \in A(q)} \exp(V_{iq})} \quad \text{Eq. 5}$$

A linear utility function is employed because it is easy to use and still approximates the true utility function well. One of the benefits of the logit model is that a number of different variables can be used to determine the utility of a particular choice to an individual. In this study, however, travel time is the only variable in use. In addition, the individual can make a choice among several alternatives, such as level of service ratings.

When a rating scheme is used, choices are assumed to be made sequentially based on the values of the observed variables. In other words, as the results of the utility function change (either increase or decrease), the choice of a user changes in sequence along the rating scale (say, from "A" to "B" to "C", not from "A" to "C" to "B"). The boundary points where an individual would be just as likely to make one choice as another can be found by setting the probability of the two choices equal:

$$P_{1q} = P_{2q} \quad \text{Eq. 6}$$

When using the logit model with travel time and perception data, it is necessary to first develop the utility relationships described earlier. The utility of each rating choice must be established, and then the standard form of the logit model can be employed to find the threshold boundaries between ratings.

Nested Logit

Nesting is used to distinguish between alternatives that are deemed similar. The need for nesting arises when it is observed that choices are made between dissimilar options based on different criteria than that used in selecting between similar options. In these cases, one logit model is used to model the choice between dissimilar options, while another is used to model the choice between similar options (13).

Consider the following case where a nested logit model is an appropriate choice. An area is serviced by both subway and bus transit to the same destination. The travel time for each is the same, and so people choose between modes based on more personal motives (the inherent utility of each mode). Two-thirds of the people choose the subway; one-third choose the bus.

A second bus line is introduced in the area. It performs exactly the same as the first bus line. It would be expected that the proportion of people using the subway would stay the same, and the bus passengers would split between the two bus lines. However, one of the properties of a logit model is called the axiom of independence of irrelevant alternatives (IIA). This axiom states that:

Where any two alternatives have a non-zero probability of being chosen, the ratio of one probability over the other is unaffected by the presence or absence of any additional alternative in the choice set (13).

The ratio of the probability of using the subway over the first bus line was originally equal to two. It would be expected that a new bus line with exactly the same characteristics as the first would experience the same ratio. It is also expected that the ratio of two exactly similar bus lines will be equal to one. However, if this is the case, subway riders will be reduced to half the population, while one-fourth will use the first bus line and another one-fourth will use the second. This is not a realistic solution.

It is more likely that two-thirds of the population will continue to use the subway and the remaining one-third will split evenly between the two bus lines. Two logit models are now needed: one to model the choice between subway and bus, and another to model the choice between the two bus lines.

The IIA axiom is an important property of the logit model that needs to be understood before applying it. Rating schemes are typically not affected by the IIA axiom because when an additional choice is introduced, the nature of each choice is redefined.

Probit

The probit model is another model based on the principle of utility. It was used by Manadat, et al., to develop a rating scheme for comfort on transit buses (15). This model makes the simplifying assumption that the random variable ε is normally distributed with a mean zero and an arbitrary covariance matrix. This assumption allows the terms to have any variance, but restricts them to a normal distribution (13).

Only two choices will be used here so that the closed form of the model can be written. Probit models that incorporate more than two choices are very difficult to write in closed form and are usually solved using numerical methods (13).

As defined earlier, the probability of choosing Option 1 is:

$$P_1(\Theta, Z) = \text{Prob}[\varepsilon_1 - \varepsilon_2 \leq V_1 - V_2] \quad \text{Eq. 7}$$

As a property of the Normal distribution, $(\varepsilon_1 - \varepsilon_2)$ is distributed univariate $N(0, \sigma_\varepsilon)$ where:

$$\sigma_\varepsilon^2 = \sigma_1^2 + \sigma_2^2 - 2\rho\sigma_1\sigma_2 \quad \text{Eq. 8}$$

Dividing $(\varepsilon_1 - \varepsilon_2)$ by σ_ε gives a standard $N(0,1)$ variate. This allows the binary probit choice model to be written concisely as:

$$P_1(\Theta, Z) = \Phi[(V_1 - V_2)/\sigma_\varepsilon] \quad \text{Eq. 9}$$

where $\Phi[x]$ is the accumulated standard Normal distribution function that is presented in tabular form in most statistics textbooks. Probit models for more choices can be developed; however, they cannot be written so easily in closed form (13).

The probit model is used in a manner similar to the logit model. Once utility functions have been developed, the probit model can be used to find the travel time where two consecutive ratings have an equal probability of being chosen. It is at this point where the threshold is defined. The probit model allows for more flexibility than the logit model; however, it is more difficult to compute, and, as mentioned before, cannot be written in closed form for a large number of choices. Table 1 compares the three models discussed in this section.

Table 1. Preference Model Comparison.

	Maximum Likelihood	Logit	Probit
Binary Data	Yes	Yes	Yes
Rating Data	No	Yes	Yes
Utility Input	No	Yes	Yes
Closed Form	No	Yes	Yes, choices ≤ 3
Software	No	Yes, needs	Yes, needs

The comparison in Table 1 shows that the logit model is the most generally applicable model for the analysis of perception data. However, any of the models could be employed, depending on the complexity of the data gathered. Also, the assumptions of each model should be checked prior to employing that model.

Perception vs. Preference

The usefulness of each of these models is heavily dependent on the type of perception data obtained. One section of this paper is devoted to a description of the means of obtaining perception data. It is important to note that these models were originally intended to model user preference, not user perception. Typically, preference data would be used to understand how users make a choice, whereas perception data would be used to understand how users evaluate the different choices they have. However, when compared, the two types of data look very similar.

Preference, or choice, data are generally recorded as either the subject user's stated or revealed preference for one choice over another. The choices are usually enumerated (Option 1, Option 2, etc.), and each user's choice is recorded.

Perception data are recorded as the rating the user would give an individual option. These ratings are usually enumerated (on a scale of one to ten, for example), and the user's perception is recorded.

The difference between preference and perception data is that while preference data reveals a user's choice given a range of options, perception data reveals the same user's opinion of that option. In addition, when the data are enumerated, preference data are always integers, whereas perception data may be continuous. The following example demonstrates the difference between perception and preference data.

Say a commuter has three options for travel from home to work. The first option is to drive; the second is to take the bus; and the third is to take the subway. If he drives, the trip will take 35 minutes. If he takes the bus, the trip will take 40 minutes. If he takes the subway, the trip will take 25 minutes. Assuming he makes his decision based solely on the trip time, he will choose the subway. Taking the subway is his preference: he prefers the subway over driving and taking the bus. Now, if he were asked to rate each mode on a scale of one to ten (ten being the best), it would be expected that he would rate the subway higher than driving, and driving higher than the bus. However, consider the two hypothetical sets of ratings shown in Table 2:

Table 2. Illustration of Perception Data.

Mode	Rating 1	Rating 2
Driving	3	7.5
Bus	1	6
Subway	6	9

The first set of ratings shows that he does not think highly of any of his choices. Riding the bus received a rating of one, the lowest possible rating. Riding the subway received a rating of six, which suggests that he barely felt that the subway had an acceptable travel time. Each mode has much room for improvement in his opinion. The second set of ratings shows a much more satisfied user. Each rating is higher than five, which indicates that the user thinks the travel times are acceptable. The subway still receives the highest rating, but the user is much more pleased with his choice. The rating of 7.5 for driving (halfway between seven and eight) shows how perception data can be continuous.

Use of Perception Data

At first, perception data may seem to be a rather imprecise form of data. The idea of relying on non-technical sources to categorize technical options may offend some of the technical elite. There are many areas, however, where the public's opinion is an invaluable tool. Politicians and businesses use opinion data to find out what the needs of the public are. Because transportation serves the public, transportation planners ought to seek the public's opinion, also.

Surveys have been used in many settings where important decisions need to be made. In transportation settings, surveys are most often used to collect data about travel patterns. Origin-destination surveys and travel diaries have been used for many years to predict understand traveler's choices and prepare for future growth. Other surveys present travelers with hypothetical situations and ask them to choose a transportation option (13).

The level of service grades used in the Highway Capacity Manual are intended to reflect the probable thresholds that users might choose. They are also supposed to bridge the gap between technical transportation analysts and the largely non-technical public. Level of service is often used as a decision-making criteria. Projects where the existing conditions exhibit a low level of service are granted higher priority than projects with a higher existing level of service. Ideally, similar level of service grades should reflect similar perceived levels of mobility, regardless of the facility type. However, no test has even been made to verify this assumption.

The assertion is often made that congestion is a relative term — relative to time, space trip purpose, and other factors. The use of perception data allows transportation planners to evaluate facilities with each of these variables in mind. While it is unlikely that perception data will change the design period (rush hour), it is possible that different standards could be employed for different types of facilities in different locations. Perception data is also consistent across facility types, so a consistent level of service could be maintained throughout a region.

Several econometric techniques exist for analysis of preference data. With random utility theory as their basis, these techniques include logit and probit analysis, among others. Logit and probit analyses have found uses in transportation planning applications, and have many other uses besides (13).

METHOD DEVELOPMENT

In this section, a potential method for combining travel time and public perception data to create a local decision-making criteria is outlined. The proposed method consists of five steps that, when completed, will result in a level of service criteria that is based on travel time and public perception data specific to the study corridor.

Step 1: Evaluate Need

It has been implied throughout this paper that an undertaking to redefine level of service criteria for an individual corridor or study area can be a difficult and expensive process. There must exist a need for such a process. This need will most often be expressed in the level of exposure the potential project receives, either from political bodies, the news media, or concerned citizens' groups. The level of exposure must be balanced with the cost of performing such a study to see if it is a worthwhile venture. It is likely that this method will not be employed except for the largest projects until methods of gathering perception data have improved.

Step 2: Collect Travel Time Data

Any of the travel time data collection techniques identified in the Travel Time Data Collection Handbook are applicable for use. Most agencies can continue to use any means that are already employed to collect travel time data without concern. The most important consideration in selecting the data collection technique is the geographic scope of the study.

It is important that these data be correlated, at least in time and space, with the perception data. While the actual travel time of the individual responding to the survey is not required, an estimate of that travel time should be made.

For large data collection efforts, ITS technologies provide the most reliable means of obtaining both travel time and perception data. The use of GPS systems, in particular, does not limit the geographic scope of the study to areas where large investments in infrastructure improvements have been made.

Step 3: Collect Public Perception Data

While the means of collecting public perception data can vary, it is very important that each response be correlated with a travel time. The most important concern in selecting a data collection method is the required sample size. Large samples can require great expenses if inefficient data collection methods are used.

The geographic scope of the study area can greatly influence the necessary sample size. In order to obtain a representative sample of travelers using a major freeway, it may be necessary to include a large number of people in the survey. On the other hand, if the geographic scope is limited to a particular intersection, the survey may be completed using only a small number of participants.

It would be most efficient to conduct a public perception survey in conjunction with some other type of survey, if it is possible. For example, if a major planning project has proposed to use travel diaries to estimate origin-destination patterns, the diaries should include a user perception survey as well. These surveys should be of the form recommended earlier in this paper, grading the facility from “Too Fast” to “Too Slow” rather than from “A” to “F” or 1 to 10.

Step 4: Employ Model

Using the travel time and public perception data gathered in Steps 2 and 3, the logit model should be employed to obtain level of service thresholds. If the data collection processes have been carefully controlled to obtain accurate information, the model should provide threshold values that can be used to evaluate options for the proposed project.

Step 5: Evaluate Options

Each of the options proposed for the project should now be evaluated using the level of service thresholds obtained in Step 4. The option that meets the appropriate level of service criteria should be chosen for the project. This choice should be confirmed by engineering judgement to ensure that the resulting project will not be excessive in cost or hazardous to motorists.

The result of this process is a set of level of service thresholds that can be applied to one particular segment of the transportation system. The thresholds can be used to help select the best option, as in Step 5, or to monitor a facility to see when conditions worsen to the point that an improvement is necessary. If another facility is deemed similar to the one under study (say, two similar intersections or entrance ramps), the thresholds can be used at both facilities to save the cost of another study.

CONCLUSIONS AND RECOMMENDATIONS

In this paper, a methodology for identifying local travel time thresholds has been presented. The benefit of this method is that it is locally calibrated and therefore reflects local conditions. There is no need to rely on nationally developed guidelines that may have little bearing on the particular transportation facility being studied.

The use of travel time data in the method allows it to be easily understood by the general public, while capturing accurately the conditions in the study area. The method also uses direct public perception data to create thresholds for decision-making. This dependence on public input makes the method more valuable to both the public and non-technical decision-makers.

Travel time meets many of the criteria for a mobility measurement suggested by Lomax and Schrank (*1*). In the past, mobility measurements have been used to develop level of service criteria for evaluating transportation facilities. Because travel time can be measured on most facilities, it has much potential for use as a performance measure for defining level of service. As a result, travel time was chosen as the performance measure for use in this paper.

While much research has been done in the area of obtaining travel time data, relatively little has been done in obtaining public perception data. An investigation of the means of obtaining this type of data in a cost-effective manner is recommended for further research.

In addition, further research is recommended for the development of specific forms of the models investigated in this paper. Software solutions for these models should be developed that would allow transportation analysts to use travel time and public perception data together to calibrate these models.

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ITS APPLICATION FOR SEVERE WEATHER CONDITIONS

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EXECUTIVE SUMMARY

Adverse weather and other harsh environmental features are common throughout the United States due to the country's vast size and diverse range of geographic characteristics. Severe winter weather, involving ice and snow occurs throughout the northern and central states and in mountainous areas of southern regions. The impacts of these conditions on highway users are considerable. Statistical analyses have shown that a disproportionate number of accidents and fatalities occur under adverse environmental conditions. It has been estimated that between 25 and 35 percent of all interurban accidents occur during adverse weather conditions.

Due to the high frequency of accidents during severe weather conditions, and the increasing maintenance costs related to these conditions, several systems have been developed to predict severe weather conditions. The objectives of this research were to evaluate the current state of practice for dealing with severe weather conditions, make recommendations as to which sensors or weather prediction systems work best in different situations, and make recommendations on the implementation of Road Weather Information Systems (RWIS) in the San Antonio, Texas area.

To accomplish these objectives a literature review was conducted encompassing all ITS applications for severe weather conditions. Several phone calls and personal interviews were also conducted due to the lack of published material in the specific area of pavement sensors.

From the findings it was recommended that the active pavement sensors be used in areas where high concentrations of salt are regularly present (greater than four percent concentration). In this situation the Climatronics FRENOR sensor is recommended. In areas where typically low concentrations of salt are present, less than four percent concentration, it is recommended that passive pavement sensors be used. The Surface System, Inc. (SSI) passive pavement sensor is recommended under these conditions. The most commonly used Road Weather Information System (RWIS) in the United States seems to be the SSI system. In situations where this system is present in neighboring states or countries, it is recommended that this system be implemented for weather prediction purposes so that information can be shared across boundaries. It was also determined that San Antonio, Texas is a good candidate for implementation of an RWIS.

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INTRODUCTION

The safety, mobility, and economic impacts of weather on transportation are considerable. The White House Office of Science and Technology Policy (OTSP) estimates that weather causes or contributes to 6,000 fatalities on U.S. highways each year. According to the General Estimate System crash database, in 1995 there were approximately 435,000 injury crashes in the United States due to adverse weather. Despite the fact that North America spends more than \$2 billion a year on snow and ice control, road accidents increase during adverse weather by a factor of from two to five (1).

Through the use of weather prediction systems not only do agencies have the ability to decrease accidents, they also have the ability decrease the amount of chemicals applied to roadways. Ice prevention, or anti-icing, requires 30-75 percent less chemical treatment than does deicing, and is much more cost-effective in snow and ice control (2). Pinet & Associates suggest that benefit-to-cost ratios resulting from the implementation of Road Weather Information Systems (RWIS) can be as high as 11 to 1 (3).

The most popular weather prediction systems in use throughout the United States and several other countries are the Road Weather Information Systems (RWIS). RWIS are defined by the federal Weather Summary and Synthesis Report as “a combination of technologies and decision making that uses weather information to apply labor, equipment and materials as cost-effectively as possible (2).” In general, the RWIS consists of on-site temperature and atmospheric sensors, data processing units, telecommunication capabilities, and workstation displays. The information typically output from these systems includes air temperature, wind speed and direction, humidity, precipitation, dew point, visibility, and road condition (wet, dry, icy). Pavement temperatures are obtained from solid-state electronic devices installed in the roadway. Surface sensors can either be active or passive, but passive sensors have gained more wide-spread acceptance with over 2,000 installed in the U.S., Canada, the UK, Europe, and Iceland (2).

Heavy snowfall not directly attributable to winter storms can also contribute to roadway accidents and damage if avalanching occurs above the roadway. Several projects around the world are in the process of testing and evaluating avalanche detection systems. These systems not only have the ability to make conditions safer for travelers, but also for the maintenance personnel working near avalanche prone areas (9).

Fog warning systems are also being tested extensively throughout the country. These systems go above and beyond the simple visual detection provided by the RWIS systems. For example, some of these systems incorporate video cameras and other visual detection technology that better predict the presence and intensity of fog (4).

PROBLEM STATEMENT

Many weather prediction systems throughout the world have been implemented trying to predict severe weather conditions before they occur. However, many of these projects are still in the developmental stages and their progress is unknown. Research is needed so that these weather prediction systems can be expanded to their full potential. Through the use of new technologies the reactive manner of dealing with severe weather conditions can be changed into a more proactive response which will decrease maintenance costs and make for a safer driving experience.

OBJECTIVES

The major objectives of this research were to:

- Identify field operational test projects related to the use of ITS technologies for severe weather conditions;
- Identify the reliability and accuracy of these technologies, specifically in-pavement sensors;
- Make recommendations on their use and effectiveness; and
- Make recommendations on the feasibility of these technologies to a traffic management program (Transguide) in San Antonio, Texas.

SCOPE

The scope of this research included all ITS technologies that have been developed with regards to severe weather conditions. These weather conditions include: wind, low visibility conditions (fog), avalanches, ice and snow. Pavement sensors reviewed included both in-pavement and out-of-pavement sensors.

BACKGROUND

Several projects around the world are being conducted with the objective to predict severe weather conditions before they occur. The projects reviewed are summarized into three categories: Road Weather Information Systems (RWIS), fog warning systems, and avalanche warning systems.

Road Weather Information Systems (RWIS)

The projects reviewed in this section are briefly summarized in Table 1. The full description of the projects are also given in this section.

ATWIS

North and South Dakota are developing an Advanced Transportation Weather Information System (ATWIS) for several of their interstate highways. Weather forecasting and analysis technologies are used to produce short-range site-specific weather forecasts using road and weather sensors and weather satellite observations. Nowcasts and forecasts are made subjectively, by people interpreting the data, and by a prediction model developed for the project that is run on a supercomputer. Forecasts are updated every three hours and cover a six hour period. The electronic forecast is converted to a speech file so that travelers can access it through cellular phones. Maintenance departments in both states receive forecasts daily through electronic mail.

Three types of data collection technologies are used to maximize data collection: Surface Systems, Inc. (SSI) weather stations, Geostation Observation Weather Satellite (GEOS) observations, and an agricultural weather system. Road and weather data are collected from approximately 30 weather stations located throughout North and South Dakota. Data collected include: pavement surface and subsurface temperature, air temperature, wind speed and direction, and pavement status (dry, wet, amount of chemicals on surface). GEOS provides surface and upper air observations and weather predictions. The agricultural mesonet is used to obtain the following data: air temperature, moisture, wind speed and direction, radiation, and precipitation. Data from the weather and pavement sensors and the mesonet are transmitted over telephone lines (4).

Table 1. Road Weather Information Systems (RWIS) Summary

PROJECT	NO. OF WEATHER STATIONS	LOCATION	MANUFACTURER
Advanced Transportation Weather Systems (ATWIS)	30	North and South Dakota	Surface Systems, Inc. (SSI)
Colorado Weather Prediction System	100 sensors	Colorado	Surface Systems, Inc. (SSI)
Road Weather Information System	22	Nevada	SSI, Coastal Environment, and Vaisala
Test & Evaluation Plan for the Effectiveness of RWIS-Based Snow and Ice Control Practices	22	Iowa	?
Washington RWIS	200	Washington	Surface Systems, Inc. (SSI)
Idaho Storm Warning System	?	Idaho	Santa Fe Systems, SSI, and Handar
Lake Tahoe Weather Information System	?	Nevada	?
Sierra Project - "Snow Wars"	4	California	Surface Systems, Inc. (SSI)
State Route 22 (Crescent Mountain) Visibility Project	1	Pennsylvania	?
TravelAid	6	Washington	Surface Systems, Inc. (SSI)
Variable Speed Limit Project	22	Nevada	SSI, Coastal Environment, and Vaisala
Visibility Warning Project	10	California	Surface Systems, Inc. (SSI)
Infrared Pavement Temperature Sensor on Maintenance Trucks	?	Indiana and Vermont	Control Products, Inc.
Thermal Mapping of Road Temperature	?	New York	Vaisala, Lockheed Martin
Off the Shelf RWIS for Rural ITS Applications	?	California	?
The Traffic Management Policy of Variable Message Signs for Weather-Controlled Road Between Pyhtaa and Hamina, Finland	?	Finland	?
Effects of Weather Controlled Speed Limits and Warning Signs of Driver Behavior	?	Finland	?
Examining the Institutional Issues Related to Implementing Road and Weather Information Systems (RWIS)	Does not apply (-)	Nationwide	-
Assessment of Road Surface Freezing Point for the UK	-	United Kingdom	?
Test of Road Weather Monitoring Systems	-	Sweden	Many
Environmental Sensor Systems for Safe Traffic Operations	-	Nationwide	Many

Colorado Weather Prediction System

Colorado is using Surface Systems, Inc. (SSI) weather stations. Approximately 100 road sensors throughout the state collect road condition data every 15 minutes that is transmitted to remote processing units (RPU's).

All pavement sensors monitor pavement temperature; newer sensors also monitor chemical concentration on the roadway and road refreezing temperature. Weather data collected includes air temperature, relative humidity, wind speed and direction, and whether there is precipitation. The newer weather monitors also collect data on precipitation accumulation and rate, traffic counts, and visibility. These data are used by SSI to prepare location-specific road and weather forecasts.

The Hanging Lake Tunnels division in Glenwood Springs, can access the RPU's in their jurisdiction in real-time. This allows the maintenance staff to provide current conditions to travelers, including commercial vehicle operators in the northwest portion of the state (4).

Road Weather Information System - Nevada

Twenty-two weather stations have been installed throughout the state of Nevada. The sensors monitor air temperature, wind speed and direction, humidity, precipitation, dew point, visibility, road condition (wet, dry, ice), pavement surface and subsurface temperature, and the amount of chemical on the roadway. The weather stations are from three different providers: Surface Systems, Inc. (SSI), Coastal Environment, and Vaisala.

Thermal maps have been prepared for 275 miles of highway in conjunction with pavement temperature measurements. The thermal maps, which remain the same over time as long as no changes are made to the topography or to the vegetation or buildings along the highway, provide for more efficient winter road maintenance.

The Nevada DOT developed a Performance-Based Training Package to educate maintenance employees on how to use the data provided by the Road Weather Information Systems (RWIS). All personnel who would use the RWIS to make decisions are trained on its use.

SSI provides localized pavement and weather forecasts based on data obtained from its weather monitors. Data from the Coastal Environment and the Vaisala weather stations are integrated into one system, allowing the NV DOT staff to use LEADS software, developed by Lockheed Martin, to prepare weather and pavement forecasts using data collected from both of these stations. Atmospheric forecasts are provided by Northwest Weathernet, a local provider.

Maintenance personnel can access the data and forecasts by computer. Based on forecasts, weather advisories are issued through variable message signs (VMS), highway advisory radio (HAR), and a local television station (4).

Test & Evaluation Plan for the Effectiveness of RWIS-Based Snow and Ice Control Practices - Iowa

The Iowa DOT developed this plan with two main goals: 1) demonstrate how snow and ice control decisions are most effectively performed using various components of Road Weather Information Systems (RWIS), and 2) evaluate the extent to which the benefits predicted by research are actually achieved. Weather data will be obtained from the state's 22 RWIS sites, as well as other public and private sources.

This plan was developed to evaluate the existing RWIS in Iowa to determine deficiencies and develop an approach to integrated RWIS implementation. Existing weather data sources will be identified and evaluated, including the 22 weather stations installed throughout the state. Three locations in Iowa were selected to be used as test and evaluation (T & E) sites. For these locations, detailed pre-, during, and post-storm snow and ice control decisions and actions will be monitored to determine their effectiveness. Also, an effort will be made to document actions that would have been taken without RWIS. The project also includes a review of weather forecast services to determine their appropriateness (4).

Washington RWIS

Approximately 200 weather stations are located along roadways throughout Washington State. The types of data collected at the stations include air temperature, wind speed and direction, and visibility. Most of the weather stations are manufactured by Surface Systems, Inc. (SSI).

The weather stations are used by maintenance personnel throughout the state; however, the stations are not connected to each other. Each maintenance section uses its own monitors. The Washington Department of Transportation is working on connecting all of the weather stations so all maintenance sections can access data from any weather station. The state is also working to put the weather data on an Internet web page (4).

Idaho Storm Warning System

Road, weather, and visibility data are collected using three different sensors which are located at the same site. Data from the sensors are downloaded to a master computer every five minutes. The objectives of the project are to evaluate and compare the performance of the three sensors. A video camera has been set up at the site to assist with sensor evaluation. If the visibility level observed by any of the sensors falls

below a threshold value, an alarm is activated. Changeable message signs are used to warn motorists of the low visibility. The data are not currently being used for forecasting. The following sensors are being evaluated (4):

- LIDAR (Light Identification and Ranging) manufactured by Santa Fe Systems-. This sensor uses a laser to measure visibility. While this sensor is more expensive per unit than the other two sensors, only one sensor is needed to monitor the visibility of a path up to 10 kilometers.
- SCAN sensor manufactured by Surface Systems, Inc. (SSI)- The SCAN sensor monitors weather and pavement conditions, including visibility, wind direction and speed, air temperature, precipitation, and pavement temperature.
- Handar sensor- The Handar Sensor monitors weather conditions only, such as visibility, wind direction and speed, air temperature, and precipitation.

Lake Tahoe Weather Information System

The goal of this project is to use an advanced weather information system to reduce the use of sand, salt, and de-icing chemicals in the Lake Tahoe Basin, which includes parts of Nevada and California. The de-icing materials enter the lake and deteriorate water quality. Weather stations, installed by Nevada DOT (NDOT), provide early warning of changing conditions. The advanced warnings allow NDOT to warn travelers of potentially hazardous weather conditions and allow road crews to place salt, sand, and other de-icing chemicals in a more timely manner. The weather station information has been used on a small scale around Lake Tahoe. Funding for this project will allow for expansion of the system Basin-wide (4).

Sierra Project - "Snow Wars" - California

Four Surface System, Inc. (SSI) weather stations, which include pavement sensors, collect data on weather and roadway conditions. Weather data include air temperature, humidity, wind speed and direction, and visibility. The pavement sensors collect data on surface and subsurface temperature, pavement condition (wet, dry, icy), and the amount of de-icing chemical on the roadway. The monitors are located at altitudes above 4,000 feet. Traffic detectors are also used to monitor traffic speeds. The Kingvale Snow Management Control Center collects the weather and traffic information.

SSI provides localized pavement and weather forecasts to the Kingvale Snow Management Control Center using the data obtained from the weather stations. In addition, weather forecasts for the region are obtained

from a local weather forecasting service, DTN. DTN monitors are located in the highway maintenance dispatch rooms of the Kingvale Snow Management Control Center.

Based on forecasts and traffic information, the Kingvale Snow Management Control Center issues traffic and weather advisories, if warranted, through variable message signs (VMS), highway advisory radio (HAR), and the California Highway Information Network (CHIN) (4).

State Route 22 (Crescent Mountain) Visibility Project - Pennsylvania

In order to improve safety on the section of State Route 22 that crosses Crescent Mountain, a weather station was placed along the roadway to monitor weather conditions. If road safety is compromised by inclement weather (snow, ice, or fog), variable message sign (VMS) are manually programmed and activated to alert drivers to the diminished roadway conditions. Two VMS are used, one located at each approach to the mountain (4).

TravelAid - Washington

Weather and pavement sensors monitor conditions along the highway through the Snoqualmie Pass. Six weather stations monitor air temperature and wind speed and direction; only two or three of the weather stations also measure visibility. The pavement sensors monitor pavement conditions and temperature. Radar traffic detectors are also positioned along the 40-mile stretch of highway to monitor vehicle speeds. Based on weather and pavement conditions and travel speeds, highway maintenance personnel can reduce speeds using variable speed limit signs (VSL), and alert travelers using highway advisory radio (HAR), variable message signs (VMS), and in-vehicle units (IVU) radio receivers with alphanumeric displays.

Surface Systems, Inc. (SSI), the manufacturer of the weather stations and pavement monitors, will provide pavement and weather forecasts to WA DOT using the data obtained from the monitors. In addition, the National Oceanic and Atmospheric Administration (NOAA) has weather sensors and provides the state with its forecasts, concentrating on avalanche potential. NOAA will incorporate data from the SSI sensors along with data from its own sensors.

The state will distribute approximately 200 IVU to state police patrols, commuters, and commercial vehicle operators. The IVU are called Traffic Master and will provide information such as weather, revised speed limits, incidents, and whether chains are necessary, as well as a map showing areas of reduced conditions. The idea of using Traffic Master in-vehicle devices is not cutting edge; however, the concept of providing in-vehicle units with weather information to travelers is innovative and not widely practiced (4).

Variable Speed Limit Project - Nevada

Twenty-two weather stations have been installed throughout the state. The sensors monitor air temperature, wind speed and direction, humidity, precipitation, dew point, visibility, road condition (wet, dry, icy), pavement surface and subsurface temperature, and the amount of chemical on the roadway. One of the weather stations is located along a portion of highway that began experiencing increased incidences of reduced visibility and reduced road surface conditions (icing) as a result of a power plant expansion. At this location, variable speed limit signs and warning signs are being installed to warn drivers of diminished road and visibility conditions.

Vehicle speeds will also be monitored along I-80, 15 miles east of Reno. The 85th percentile speed will be calculated based on prevailing traffic conditions. Data from the RWIS will then be used to calculate the appropriate speed from current weather conditions. This speed will be shown on the variable speed limit signs. If speed limits are reduced, signs will be activated that read "Reduce Speed When Flashing."

Data from the weather station are sent to the central processing unit, allowing the NV DOT staff to use LEADS software, developed by Lockheed Martin, to prepare weather and pavement forecasts. Maintenance personnel can access the data and forecasts by computer (4).

Visibility Warning Project - California

Ten Surface Systems, Inc. (SSI) weather stations, which include pavement sensors, collect data on weather and roadway conditions. Weather data includes air temperature, humidity, wind speed and direction, precipitation, dew point, and visibility. The pavement sensors collect data on surface and subsurface temperature and pavement condition (wet, dry, icy).

SSI provides localized pavement and weather forecasts based on data obtained from the monitors. Maintenance personnel can access the data and forecasts by computer. Based on forecasts, weather advisories are issued through variable message signs (VMS).

Closed circuit television (CCTV) cameras are located at two of the weather stations along Interstate 5 to verify visibility readings from the monitors. This portion of the highway is prone to dust storms in the spring (4).

Infrared Pavement Temperature Sensor on Maintenance Trucks - Indiana/Vermont

The goal of this project is to increase the efficiency of applying anti- and deicing materials to the road surface. An infrared (IR) sensor is installed on maintenance patrol trucks to monitor pavement temperatures. As the truck travels at highway speeds, continuous pavement temperature readings are displayed inside the truck cab. Material application rates are based on pavement temperature and maintenance staff estimates of the ice or snowpack thickness. This system has been used in Vermont and Indiana. Vermont's sensor supplier is Control Products, Inc. (4).

Thermal Mapping of Road Temperature - New York

A thermal profile of roadway sections will be developed based on road surface temperature readings obtained from sensors in the roadway. This will provide maintenance personnel with information on which areas of the roadway are prone to freezing before other areas. This information can be used to provide more efficient winter road maintenance.

Two technologies will be used to create thermal maps of about 130 miles of highways in the state. The results from the two methods will be compared, and the accuracy of both methods will be evaluated against actual pavement temperatures.

Conventional thermal mapping will be performed by Vaisala. Their method involves conducting a route survey to identify characteristics of the roadway which may affect the temperature, such as trees or tall buildings. A vehicle with an infrared sensor will then be used to collect pavement temperature data. Approximately five thermal surveys will be made for each weather category (calm and clear, windy and cloudy, and intermediate conditions). Thermal maps, which will be prepared for each weather category, will be provided in paper format and in digital form for use on a PC.

Lockheed Martin will perform thermal mapping using innovative technology that is considerably less expensive per mile than Vaisala's method. An infrared sensor and a global positioning system (GPS) will be used to record thermal data. Pavement temperature and outside air temperature will be recorded with a Sprague Controls ROADWATCH road and air temperature sensor mounted on the truck. A Trimbel SvecSix GPS receiver will record latitude and longitude. Approximately five surveys will be made for each weather category (damped, intermediate, and extreme). Temperature differences for each segment and weather

category will be prepared and entered into the Modified Central File Server. The data can be viewed using PC-based software (4).

Off the Shelf RWIS for Rural ITS Applications - California

WELS Research developed a two-part software package that provides detailed forecasts of surface weather conditions customized for specific regions. Part I uses National Weather Service (NWS) raw observational weather data to produce 24-hour weather forecasts for the U.S. The software also produces forecasts for subareas (for software users). The subarea forecasts are produced twice daily. Part II of the software is accessed by the users. It provides a user-friendly, interactive display of the forecasts.

This software is unique in two ways. The first is that it provides an interactive graphics user interface which allows users to input actual conditions and change forecasts. The second innovation of this software is that the forecast algorithm, which provides results similar to that of the NWS, runs on a desktop personal computer (with a pentium processor) whereas the NWS program runs on a supercomputer (4).

The Traffic Management Policy of Variable Message Signs for Weather-Controlled Road Between Pyhtaa and Hamina, Finland

The Finnish National Road Administration has used road transport telematics on a weather-controlled road to reduce problems caused by bad weather and road conditions. The weather-controlled road stretches between Pyhtaa and Hamina for 25 kilometers along a section of European road E18 on the southern coast of Finland. Along the E18 roadway drivers are informed about varying weather and road conditions in real time through automatic road weather monitoring stations and variable message signs. The weather-controlled road contains five automatic road weather monitoring stations, 66 variable message signs and 13 variable warning signs. The weather-controlled road aims to improve the efficiency and safety of transport as well as to increase traveling comfort by controlling variable message signs according to existing road conditions.

The sensors connected to the road weather monitoring system measure wind speed and direction, air temperature, roadway surface temperature, humidity, intensity and state of precipitation, visibility, and road surface state (wet, dry, icy). The mainframe computer collects road weather information and warnings from road weather monitoring stations for data storing and analysis in five minute intervals. Road weather information are then analyzed and assigned to four road condition categories A, B, C, or D. Category A is the good road condition category which includes conditions where the road is dry or moist and no deviations are observed from summer like road conditions. Category B is the normal conditions category. The poor road condition category C includes situations of clearly worsened conditions. The very poor road conditions category D means that the conditions are very severe.

The effects of the weather-controlled variable message signs were studied. Ninety-five percent of the drivers studied expressed that varying speed limits according to prevailing road conditions was useful and enhanced traffic safety. The weather-controlled traffic management system helped decreased both the mean speed and the standard deviation of speeds along this section of E18 in Finland (5).

Effects of Weather Controlled Variable Speed Limits and Warning Signs on Driver Behavior - Finland

As part of phase two of the previously mentioned paper, this study was designed to investigate the effects of weather controlled speed limits and slippery road signs on driver behavior on Finnish road E18. Local weather and road conditions were monitored from two unmanned road weather stations. The speed limits were lowered automatically in adverse road conditions and in some cases slippery road signs were displayed as well. Speed and headway data were obtained from loop detectors. The results showed that in winter time the change of the posted speed limit from 100 km/h to 80 km/h decreased the mean speed of cars traveling in free-flow traffic by 3.4 km/h, in addition to the average mean speed reduction of 6.3 km/h caused by the

adverse weather and road surface conditions. When the poor road conditions were difficult to detect, i.e., there was no rain or snowfall or the rain was insignificant, the effect was 1.9 km/h higher (i.e., the reduction was 5.3 km/h). When the road conditions were such that the slippery road sign was also displayed, the system reduced the mean speed by 1.8 km/h, while the reduction of the weather was 9.3 km/h. In addition to the effects on the mean speed, the lowering of the speed limit decreased the speed variance, but had no remarkable effect on headways. The main implication of the study was that the system improved traffic safety by decreasing the mean speeds and speed variation.

System reliability is a key factor in influencing driver behavior. Therefore, the system reliability for this study was evaluated. 139 observations of the weather and road conditions were collected, as well as friction measurements. In 70% of the cases, the speed limit and the use of the slippery road sign was estimated to be appropriate. Furthermore, the results indicated that there was a tendency to use speed limits that were too high. In 26% of the cases the speed limit was assessed to be too high or the slippery road sign was not displayed when it should have been (6).

Examining the Institutional Issues Related to Implementing Road and Weather Information Systems (RWIS)

Aurora, a multi-agency consortium consisting of several state DOT's and federal agencies, funded this project aiming to identify and document institutional issues relating to the implementation and development of RWIS. From the research, the issues that were encountered could be classified into four categories: funding, staffing, partnerships, and the expandability, transferability, and compatibility of RWIS systems.

Funding. The key to resolving funding issues may be the ability to present the benefits of implementing RWIS and how it can improve maintenance activities within an agency. At the outset of RWIS implementation, agencies should draw upon the previous experiences of others and present to their organization a clear picture of how RWIS can benefit their agency. As with securing funding for any endeavor, the competition of funds will be a constant struggle. However, if it can be widely understood within implementing agencies that RWIS can significantly improve the efficiency and appropriateness of maintenance and operation procedures, these technologies should eventually evolve into a well-accepted tool in the snow and ice control process.

Staffing. In some instances, RWIS innovations have been perceived negatively, as another tool to replace manual labor. Additionally, winter storms have not been perceived by maintenance staff as being an unfortunate experience. The conviction was that if RWIS can be used effectively in snow and ice control activities, it would reduce the amount of overtime money (7).

The negative mindset of some personnel is an obstacle that may be overcome by adequate training. It is apparent that training is required initially to alleviate resistance to using RWIS technologies, and continually to increase levels of familiarity and comfort. From the surveys that Aurora conducted, there was found to be a noticeable void and training is not emphasized like it should be. In the cases where training has taken precedence, personnel are generally openly embracing RWIS technologies.

Partnerships. Although there is tremendous interest in partnerships, there appears to be some hesitation by public agencies to form partnerships with other private and public agencies. The prevailing reluctance stems from liability and ownership issues. Additionally, partnerships proved to be largely uncharted territory for agencies within the United States, particularly public/private ventures.

Before public agencies seek out partnerships, they must determine the needs of their potential partners and be able to clearly define the roles each will play and how each will benefit from the alliance. For instance, private sector partners need to be confident that their cooperative venture will prove profitable. However, it is recognized that government agencies need to maintain the competitive bid process and be continually cognizant of not intentionally favoring one company over another in the quest for potential partners.

Furthermore, clearly delineated roles and responsibilities in the ownership of data can alleviate some of the potential areas of conflict within partnerships.

Expandability, Transferability, and Compatibility. Incompatibility of various RWIS sensors and systems is a primary concern since public agencies are looking towards deploying a network of RWIS technologies. Not only is it an issue with the boundaries of a state, but it appears to be problematic for neighboring countries who would like access to centralized road and weather information to aid in maintenance activities along common boundaries. Presently, the technology exists to implement RWIS at a statewide and even nationwide level, but the incompatibility of systems from different vendors is one factor which impedes full-scale deployment at an acceptable cost.

Agencies should attempt to remain abreast of the RWIS-related protocols and standards development process by becoming actively involved with the organizations and committees established to deal with these issues. Being involved in these activities encourages proactive problem solving and reaching solutions which meet the needs of a broad range of organizations. Also, by directing energy into standardization and protocols, duplicate efforts can be minimized by having cooperative participation by numerous agencies.

Conclusions. From the perspectives of the agencies that were interviewed, perhaps the greatest challenges are training of operations and maintenance staff and the shortage of funds to provide sufficient and proper equipment. In addition, changing the cultural climate of agencies and mindsets of those decision-makers who have control of funding that could be utilized for RWIS are other impediments to advancing RWIS technologies. The lack of coordination between agencies with parallel efforts was seen as an obstacle for widespread implementation of systems.

Although there appear to be many hurdles to clear, RWIS programs prove to be successful and beneficial to public agencies. RWIS is a valuable tool in the winter maintenance decision-making process. The information gathered from these systems and distributed to maintenance staff and the general public cannot reduce the severity of weather and winter storms. However, it can help reduce the effects from such storms (Z).

The following three papers deal with evaluations of different sensor technologies.

Assessment of Road Surface Freezing Point Sensors for the UK

Between 1992 and 1997, the Transportation Research Laboratory was commissioned by the UK Highway Agency to assess whether the displayed freezing point temperatures (FPT) from different systems were consistent and accurate, taking into account the residual deicing chemical on the road. A series of experiments on in-service roads monitored the performance of both existing types of sensors (passive and active) installed in the highway. Two test methods were adopted: spraying and ponding of the salt solution directly onto the sensor. Each test was carried out with increasing concentrations of salt solution before final washing off to determine the ability of a sensor to recover. To increase confidence in the results found on the road, the sensors were tested under controlled laboratory conditions. The purpose was to investigate the ability of the sensors to detect the freezing point (or concentration) of 0.5 mm thickness of aqueous rock salt solutions under idealized conditions.

The performance of passive sensors, on UK roads, shows that the FPT's of applied salt solutions at ambient temperatures at and below 2°C are slow in response and salt solutions are not accurately measured when the concentration is above four percent. Increasing salt concentrations are measured more accurately than decreasing salt concentrations.

The active sensor performed satisfactorily and measured the FPT accurately at test temperatures of 2°C and -5°C for applied salt solutions of 0, 3.8, and 10.7 percent concentration. In general, the sensor responded

quickly to changes in salt concentration and test temperatures and performed better than the passive sensors under this test procedure (9).

Test of Road Weather Monitoring Systems and Sensors - Sweden

As part of COST 309, the Swedish National Road Administration (SNRA) conducted an objective study comparing four different roadway weather systems and sensors. The four different systems compared were the van den Berg BV & BG Engineering Ice Warning System, the CDS/Campbell Weather Monitoring System, the FFV Road Weather Information System, and the Thies Weather Monitoring System (11).

Surface Temperature. Although no comparisons were made between the different road temperature sensors, some general comments were made with regards to these sensors. The most common type of sensor for measuring road surface temperature is the pt100-sensor. This sensor measures the electronic resistance over a platinum thread usually placed in a steel tube. The accuracy for this sensor has been shown to be good, less than ± 0.2 °C. Another widely used surface temperature sensor is the *Thermocouple* sensor. This sensor is inexpensive and only consists of the wires between the logger and the road pavement. In some applications an IR-sensor can be used, mounted above the road. However, this sensor is expensive and is not useful in ordinary road monitoring systems.

The location of the road surface temperature sensor is very important. The high speed lane (with less traffic) is often some degrees cooler than the low speed lane. Within the lane, the temperature differs between the wheel tracks, the area right under the car, and the area just beside the car. In the Swedish system, the sensors are located in the middle of the lane between the two wheel tracks. If the sensors were located in the wheel track, the studs from the tires would wear out the sensor too fast.

Humidity. There are two purposes for measuring humidity when monitoring road conditions. First, it gives general information about the weather conditions. Second, by comparing road temperature and dewpoint temperature, one sees the conditions for dew and frost.

The Rotronic YA 100 and the MP-100F both utilize the same sensor (Hygromer). It is very small, approximately 0.002 grams. It can measure the relative humidity from 0% to 100% and operate at temperatures of -50°C to +150°C. The values of the relative humidity from these sensors did not differ significantly from the values of the sensor installed in 1989/1990 (11).

The Thies hygro-thermo-transmitter was also tested for accuracy. The concern for accuracy occurs when the humidity is between 85-90%. The paper suggests that this sensor, a hair transmitter sensor, needs to be recalibrated somewhat more often than electronic sensors and that the accuracy is best when the humidity is not close to saturated. The calibration should be done in the field because the indoor ambient air temperature can affect the hygrotransmitter (11).

The FFV Road Monitoring System uses Lambrechts hair hygrometer, 809L-100 with a synthetic hair-element (PERNIX). This sensor is identical to the one manufactured by Friedrich. The Swedish Road Administration have had good experience with this sensor and have used it for several years. Usually they recalibrate it once in the beginning of the season, once in the middle, and occasionally some extra calibration is needed (11).

Freezing Point and Road Condition. BG Engineering uses a circular shaped sensor, 6 cm in diameter that is mounted flush with the road surface. The sensor measures the conductivity of the road surface emulsion, using two concentric steel pipes. It is recommended that when these sensors are used, the system should not classify the road condition automatically but rather present the value of the conductivity. The road officers themselves then can classify the road condition, using information both from the road sensor and from other sources (11).

The FFV Frensor sensor is an active sensor which directly measures the freezing point temperature of the road surface film. The size of the device is 40 X 80 X 80 mm, and is made of epoxy and stainless steel. This sensor showed very good accuracy, and after an adaption of the linear error, the total error is less than tenths of a degree (11).

Environmental Sensor Systems for Safe Traffic Operations

Castle Rock Consultants went into great detail comparing different weather prediction sensors. For the purposes of this paper, the discussion is limited to pavement sensors.

Climatronics (U.S.)-FRENSOR. This is an active device that is imbedded into the concrete and directly measures the freezing point using a peltier element. As earlier stated, the Swedish National Road Administration COST 309 report indicates that the freezing point is accurately measured by the FRENSOR sensor.

Surface Systems, Inc. (U.S.) - SCAN. The SCAN sensor is an in-pavement sensor that measures temperature, determines if the road surface is wet or dry using a capacitive technique, and measures conductivity to determine salinity. The sensor is thermally passive and fabricated using materials with the same thermal characteristics and color as the roadway. The system has been well tested and is in widespread use with over 200 installations reported. The cost of each ice detection station, including commissioning and installation, is approximately \$35,000.

Vaisala (Finland) - Road Surface Sensor DRS12. This sensor, normally connected to a Vaisala MILOS weather station, is passive and buried into the roadway surface. The thermodynamic properties and thermal emissivity are designed to match the roadway so that the sensor's thermal measurements match the roadway.

AANDERAA Instruments - RoadSurface Temperature Sensor (3304) and Conductivity Sensor(3330). This conductivity sensor uses four copper electrodes to measure the conductivity of any moisture present on the sensor. The sensor must be located in the roadway shoulder because only a thin film of moisture can be present.

The temperature sensor is mounted flush with the road surface in the travel lanes. The sensing element is a platinum resistor in a Wheatstone half-bridge. Only the surface temperature is measured and not a below-grade temperature. The road temperature and conductivity sensors together determine the freezing point.

Findlay Irvine (Scotland) - Road Surface Sensor. This sensor is mounted flush with the road surface and measures surface temperature, surface condition (dry, wet, ice/snow), and freezing point. The freezing temperature can be measured to four levels: 0°C, -3°C, -6°C, -10°C.

BG Engineering (Holland) - Road Condition Sensor. This device measures conductivity of the road surface. The sensor is 60 mm in diameter and consists of two concentric steel pipes. It is mounted flush with the roadway and measures the conductivity of the roadway emulsion using the inner and outer pipe as electrodes. Using this sensor it is difficult to determine the difference between dry conditions and icy conditions since dry and ice conditions both have low conductivity. One way around this is to use two sensors, one heated and one not.

Vibrometer SA (Switzerland). The Vibrometer is a steel pavement sensor which is 50 mm in diameter which determines the presence of moisture by constantly vibrating a surface plate. Analysis of the vibration determines if the road surface is dry, moist, or frozen. The surface plate is cooled and warmed using a peltier element. The phase change from ice to water is used to determine the freezing point rather than from water to ice to avoid problems with supercooled water. How accurately the sensor measured water and ice films

was not determined, but the study indicated there was a good correlation between indicated and actual film thickness.

Schrack System, Inc. (Austria) - Road Condition Radar (RCR). Road radar has the potential of measuring the thickness of the water layer and the salinity of the solution, from which the freezing point can be calculated. A radar transmitter bounces energy off the highway at a 60° angle of incidence into a microwave receiver. The radar device has an advantage over in-pavement sensors because it looks at a large area of the road across the width of the highway. Advantages are that the pavement is not disturbed during installation, and a longer sensor life can be seen since no traffic wear occurs on the sensor.

Fog Warning Systems

Fog Warning System - Georgia

Sensing equipment will be used to monitor visibility. When visibility falls below a preset level, variable message signs (VMS) will be activated automatically to alert drivers of the low visibility conditions ahead and variable speed limit (VSL) signs will show reduced speed limits.

Two visibility sensors will be used at one location. Both use forward scatter technology, however, one is standard size and the other, developed through the federal Small Business Innovative Research (SBIR) program, is smaller and cheaper than standard meters (4).

Fog Warning System - Utah

Sensing equipment will be used to monitor visibility and traffic speed. When visibility falls below a preset level, variable message signs (VMS) will be activated automatically to alert drivers of the low visibility conditions ahead and variable speed limit (VSL) signs will show reduced speed limits based on visibility and actual traffic speeds. The visibility sensors will use forward scatter technology (4).

According to the principle investigator, this project has experienced some equipment troubles that will need to be ironed out before full implementation.

I-526 Fog Mitigation Project - South Carolina

One weather station and five fog detectors are used to monitor the visibility of a section of I-526 which crosses the Cooper River in South Carolina. When sensors indicate that visibility is reduced, the maintenance dispatcher observes the location from a video camera to verify the monitor readings. If visibility is reduced, the dispatcher turns on the roadway lights and activates an appropriate message on the VMS. The roadway lights are airport lights which have been embedded in the roadway to assist drivers during reduced visibility conditions.

The weather station, manufactured by Met One, measures wind direction and speed, air temperature, and relative humidity. The five fog detectors use back scanner technology (4).

I-75 Fog Detection/Warning System - Tennessee

This project encompasses a 3-mile fog prone area of Interstate 75 at the Hiwassee River crossing and 8-mile approaches on each side. The project was initiated as a result of a fog-related accident that occurred in 1990 and involved 99 vehicles and resulted in 12 fatalities and 42 injuries. During the first two years of system operation (1993 - 1995), no fog-related accidents were reported.

Eight visiometers (fog detectors) and two weather stations monitor conditions near the fog prone area. When conditions reach levels conducive to fog generation, personnel at the Central Control Center (CCC) at the Highway Patrol Office in Tiftonia, Tennessee, are automatically alerted. Safety personnel can then activate any of 10 Variable Message Signs (VMS) along with the flashing lights on the fixed message signs. The VMS are programmed with pre-determined messages, including warnings, speed limit changes, notification of activation of highway advisory radio (HAR), and activation of six swing gates on on-ramps if the highway is closed. Variable speed limit signs are used along this portion of I-75 so the posted speed can be reduced, if necessary.

This stretch of roadway is also equipped with 44 radar vehicle flow detectors which monitor speed and number of vehicles. When either of these two parameters reaches a pre-determined level, the VMS are automatically activated to notify travelers.

The system was designed to require minimal staffing requirements. As such, safety personnel were able to incorporate the operation of this system into their daily responsibilities.

Communication between system components on-site is provided by buried fiber optic cable. Data are transmitted by microwave through the two repeater sites to the CCC in Tiftonia (4).

Avalanche Warning Systems

Technical Applications in Avalanche Hazard Mitigation - Utah/Wyoming

This project consists of two parts, monitoring traffic in avalanche-prone areas and sensing the onset of avalanches. A traffic monitoring system will be developed to monitor a two-way, two lane segment of highway. The system will count the number of vehicles entering and leaving the highway segment. If an avalanche occurs, highway maintenance personnel will be able to determine if any vehicles are trapped by the avalanche.

The second part of the project involves using and evaluating avalanche sensors. (Project participants anticipate using different sensors in this project from those used in the Idaho Automatic Avalanche Sensing System project described later in this paper). The sensors to be used for this project as of 1997 had not yet been selected. While the sensors that will be used are available commercially, they have not historically been used for avalanche detection. Thus, the project could be considered state-of-the-art.

Initially, sensors will be used to detect the onset of an avalanche. If any funding remains, the project may also include evaluation of sensors that monitor precursor conditions to an avalanche which would further increase traveler safety (4).

Development and Trial Deployment of an ITS Avalanche Hazard Management System - Utah, Wyoming, Idaho

Increased travel demand on the winter/alpine roads of the Western United States has resulted in a dramatic increase in the hazard to motorists and maintenance section personnel from snow avalanches. As part of the ITS Ideas Deserving Exploratory Analysis (IDEA) project, this study was established to evaluate three sites in the northwest that currently have avalanche prediction systems in place. The three sites being evaluated are: Idaho State Highway 21, the Canyon Creek section; Utah State Route 210, Little Cottonwood Canyon; and Wyoming/U.S.R. 189-191, Hoback Canyon (8).

The IDEA concepts investigated and reported for this study include the testing and integration of technology to manage the avalanche hazard to motorists and maintenance section personnel using an automated system. This includes sensing the initial release of the avalanches in conjunction with automated traffic management

actions along the hazardous roadway corridor. These data are then used in one of two ways: On many roadways avalanche descent times from their starting zones to the roadway below are upwards of 10 to 120 seconds. In these situations sensing the initial release of the avalanche will allow the road, which will very shortly be overrun, to be closed prior to the avalanche's arrival. Typically, the length of road which will be overrun is on the order of 100 to 200 feet. This form of knowledge based ITS avalanche hazard management is known as *time-of-descent* management. Alternatively, the avalanche starting zones may be relatively close to the road or, as is often the case, the hazardous corridor is made up of numerous avalanche paths in close proximity. In this case sensing the onset of avalanching is used to initiate closure of the entire corridor and to simultaneously notify highway and emergency management agencies. This form of knowledge bases ITS avalanche hazard management is known as *corridor* management.

Utah S.R. 210/Alta Test Bed. On Utah S.R. 210 in Little Cottonwood Canyon near the community of Alta, an operational Utah Department of Transportation avalanche road closure gate was equipped with a wireless communication interface (cellular phone) and photo-voltaic electrical re-supply capabilities. Using alpha-numeric menu commands, either manually input or from an avalanche detection sensor, it was possible to close (or open) this avalanche road closure gate remotely. The structure was destroyed by an avalanche during the winter of 1997/1998 and was not replaced (8).

Wyoming/U.S.R. 189-191 Time-of-Descent System. Wyoming/U.S.R 189-191 in the Hoback Canyon has a specific avalanche path that has a history of striking highway maintenance and motorist vehicles on the roadway. This avalanche path is long and the descent time of the avalanche is on the order of 30 seconds. The avalanche detection elements of the system are located 800 feet above the roadway. These sensors are limit switches. When the sensors are excited a radio frequency (RF) communications interface is enabled and an alarm is sent simultaneously to the lights of motorist information signs on either side of the avalanche path, and to any of several in-vehicle audible avalanche alarm boxes that can be located in highway maintenance vehicles that may have need to be working on the roadway immediately below the avalanche. This ITS avalanche hazard reduction system provides highway maintenance personnel and road users around 12 seconds of warning prior to the arrival of the avalanche on the roadway. During the 1998/1999 season, WyDOT personnel recorded four avalanche events. Of these four avalanches, at least two were successfully detected. In addition, there was one false alarm, most likely due to wind generated motion of the avalanche detection sensor, and one avalanche which occurred that was not successfully detected. The unsuccessful detection was a result of the avalanche starting below the sensor line (8).

Idaho S.H. 21 Corridor. Highway maintenance and emergency management agencies along this route are in need of real time notification on the onset of the avalanche process. This route is the only all season route connecting the Stanley basin area with the Boise area. The alternative route adds around three hours to a one way trip. There are over 50 separate avalanche paths over an 18 mile stretch of roadway. As part of this study, two avalanche detection sensors systems were installed along this route. One of the two sensor sites experienced several problems with the equipment and due to the conditions the data from both of the sensors had to be down loaded manually after the season. It is suspected that the sensors, while operational, successfully predicted avalanching. However, the snowfall was so heavy during the 1998/1999 winter season that the highway was closed and therefore no visual confirmation could be given for sensor predicted avalanches (8).

ROAD WEATHER INFORMATION SYSTEMS

There are several major manufacturers of weather prediction components; Surface Systems, Inc., Vaisala, and Climatronics are three of the most popular. This section summarizes the components and the prediction capabilities of a typical RWIS.

The RWIS consists of on-site temperature and atmospheric sensors, data processing units, telecommunication capabilities, and workstation displays.

Surface (Pavement) Sensors. Pavement temperatures are obtained from electronic devices installed in the roadway. Surface sensors can either be active or passive, but passive sensors have gained more wide-spread acceptance.

The thermally passive surface devices are usually fabricated of material with thermal characteristics similar to those commonly used for pavement contractions. Sensors, Typically 13 centimeters in diameter, are installed in a 14 centimeter diameter hole flush with the pavement surface and color matched with the surrounding pavement so that both respond to incident light energy at the same rate. The sensor's output signal is designed to reflect the condition on top of the device, which closely approximates conditions on the surrounding pavement surface;

- Dry
- Wet (above 0 degrees C)
- Wet (not frozen but at or below 0 degrees C)
- Snow/ice alert (at or below 0 degrees C)
- Dew
- Frost
- Absorption

Other measurements include a chemical concentration factor (a relative indicator of the deicing or anti-icing chemical present in the moisture on the sensor surface). Sensors typically have a stable operating range from -30 degrees to 50 degrees C.

Subsurface Temperature Sensors. Probes are installed directly below the surface sensor at a depth of around 40 centimeters. These provide heat flux information primarily for computer models designed to predict pavement temperatures. Frost depth data are also used by highway agencies to regulate truck routing on the basis of the frost level beneath the road surface.

Atmospheric Sensors. Air temperature is typically measured over a range of -62 degrees C to 70 degrees C, and relative humidity (RH) measurements over a range of 10-100%. Dew point is calculated from temperature and RH readings. Precipitation is detected by sensing interruption in an infrared optical beam. Wind direction and speed detectors have an operating range of 360 degrees and can record speeds of up to 215 km/h.

Data Processing Units. All data collection by the sensors are transmitted to a remote processing unit (RPU), which in turn converts the analog signal into a digital format and relays the information to the central processing unit (CPU). The RPU can typically receive data from up to four surface sensors, four subsurface sensors, and the atmospheric sensors. Atmospheric sensor measurements are used in the system logic processed by one or several RPU's. Agencies configure RPU's in various ways. Airports, for example, typically have 2-15 RPU's; there are 178 in the highways surrounding Columbus, Ohio; and 32 are in service in the Wisconsin statewide road weather information system (2).

The CPU analyzes, stores, and arranges the data it receives from up to 100 RPU's for information display on the workstation. The workstation displays the location of each RPU and surface sensor, the surface status of each sensor, atmospheric sensor data, and the current date and time. The system can typically update this information every 15 seconds.

Communications. Several telemetry options are available for system configuration, including dial-up and leased telephone lines, radio, microwave, fiber optics, satellite, and value-added networks.

Workstation Formats and Displays. In addition to displaying the information in tabulated test formats, the systems can provide customer-specified individualized color graphics. Critical pavement conditions are color coded for instant recognition of situation that may require proactive decisions (2).

Figure 1 below shows a typical atmospheric and temperature sensor station. Figure 2 shows the installation of a pavement sensor.



Figure 1. Atmospheric and Temperature Sensor Station



Figure 2. Installation of an SSI Pavement Sensor

RECOMMENDATIONS

From the literature review it can be seen that implementation of an RWIS can not only increase safety, it can also significantly decrease maintenance costs. One article states that the benefit to cost ratio of implementing an RWIS can be as high as 11 to 1 (3). With this in mind, it should be noted that some systems and sensors work better in certain situations than others.

One of the purposes of this paper was to make recommendations on which pavement sensors to use in different situations. It is recommended that active sensors be used in areas where high concentrations of salt typically are applied to the roadways (greater than four percent concentration). One sensor in particular is the Climatronics FRENOR sensor that has been used several places throughout the U.S. The SSI active pavement sensor would be recommended for this situation because more of these systems have been implemented and incompatibility would not be an issue. However, no analysis of this sensor was found and therefore the reliability and accuracy is not fully known.

In areas where typically low concentrations of salt are regularly present, less than four percent concentration, it is recommended that the SSI passive pavement sensors be used. These sensors have been shown to be accurate and reliable in this situation. As stated above, the SSI sensors are in wide-spread implementation across the United States and implementing these sensor technologies avoids problems with compatibility and allows full information exchange.

With regards to the implementation of full RWIS systems. Each situation is different. For general weather information and prediction, the SSI system has been shown to be accurate and has had good acceptance among agencies. However, in situations where fog is a major cause of traffic problems, other technologies should be implemented to help mitigate these problems. Several different systems have been shown to be effective using forward scatter techniques.

The different types of severe weather events that can be experienced along the roadways pose unique problems. The different ITS technologies that have been developed to help predict these events are also unique. Therefore, it seems ambitious to think that there will ever be one system that works best for all weather situations. For best results when implementing these weather prediction systems, it is recommended that a good blend of accuracy and compatibility is used to maximize the benefits of these systems.

RWIS IMPLEMENTATION CRITERIA

From the literature review a set of criteria for selecting RWIS implementation locations was developed. The issues listed below are issues that need to be addressed before implementing an RWIS system. These criteria can help agencies decide whether or not they should implement such a system.

Funding

Being able to acquire funding for RWIS projects can be difficult. The key issue is being able to present the benefits of implementing RWIS and how it can improve maintenance activities within an agency. Drawing on previous experiences of others and being able to present to your organization a clear picture of how RWIS can benefit your agency is also advised. The general idea is that if it can be widely understood within implementing agencies that RWIS can significantly improve the efficiency and appropriateness of maintenance and operation procedures, these technologies should eventually evolve into a well-accepted tool in the snow and ice control process.

With these issues in mind, it is recommended that any agency considering implementation of an RWIS system should have a public relations type of person on staff. Significant time and effort needs to be spent organizing and presenting an RWIS so that acceptance is widespread. Not only should this person be able to devote all their time to such an effort, they should also have good communication skills and training so that the plans and objectives of the implementing agency are clearly and concisely presented.

Staffing

In some instances, RWIS innovations have been perceived negatively, as another tool to replace manual labor. The conviction was that if RWIS can be used effectively in snow and ice control activities, it would reduce the amount of overtime money paid to maintenance crews.

The negative mindset of some personnel is an obstacle that may be overcome by adequate training. It is apparent that training is required initially to alleviate resistance to using RWIS technologies, and continually to increase levels of familiarity and comfort. For this reason, any agency thinking about implementing an RWIS needs to have the ability to develop a training program for personnel. This training program can be developed using in-house personnel or personnel from elsewhere depending on what is best for the sponsoring agency.

Partnerships

Although there is tremendous interest in partnerships, there appears to be some hesitation by public agencies to form partnerships with other public and private agencies. The prevailing reluctance stems from liability and ownership issues. Before public agencies seek out partnerships, they must determine the needs of their potential partners and be able to clearly define the roles each will play and how each will benefit from the alliance.

In order for an agency to be successful in implementing an RWIS system it is beneficial that they have good relationships with other public and private agencies in the area. If good relationships are not present, it should be determined if anything can be done to make the relationships work. Each area is unique when it comes to partnerships, therefore, each situation needs to be looked at to determine how past experiences with partnerships have turned out.

Expandability, Transferability, and Compatibility

When deploying an RWIS incompatibility between components of various RWIS sensors and systems is a primary concern. Not only is it an issue within the boundaries of a state, but it appears to be a problem for neighboring countries who would like access to centralized road and weather information to aid in maintenance activities along common boundaries.

When an agency is determining which RWIS sensors they should implement, the agency needs to determine which sensor technologies are already in place and which other agencies might consider accessing the information. In practical terms, this should be taken to the statewide or possibly even the multi-state level.

SAN ANTONIO, TEXAS CASE STUDY

As part of a case study, the city of San Antonio, Texas was chosen to determine if an RWIS should be implemented, and more specifically should pavement sensors. Transguide, the traffic management center in the area, has expressed interest in RWIS technologies and asked if an analysis could be conducted.

Pavement sensors aid in the prediction of roadway surface conditions, typically ice formation. However, due to the fact that San Antonio only experiences icy conditions between 0 and 8 days per year, the focus of this case study is on the RWIS system as a whole and not just the roadway sensors. The storms that pass through the San Antonio area typically have no set arrival pattern or approach direction. Therefore, to accurately predict conditions around the city, a pattern of weather stations would have to be implemented around the city on several of their major arterials. The criteria that were developed in the previous section were applied to the San Antonio area and the results are listed below.

Funding

With the geographical make up of San Antonio and the network of roads surrounding the city, it is suggested that a minimum of five stations be installed on incoming routes outside of loop 410: one on I-10 northwest of town, one on I-35 northeast of town, one on I-10 east of town, one on I-37 southeast of town, and one on I-35 southwest of town. Concentrations of salt along the roadways in San Antonio are low, for this reason it is suggested that the SSI RWIS with passive pavement sensors be installed at the five locations previously mentioned. A conservative estimate of cost of these systems is \$50,000 per system or a total implementation cost of around \$300,000. This does not include annual maintenance costs.

The following figure shows a map of San Antonio, Texas and the proposed RWIS locations (indicated by the stars).

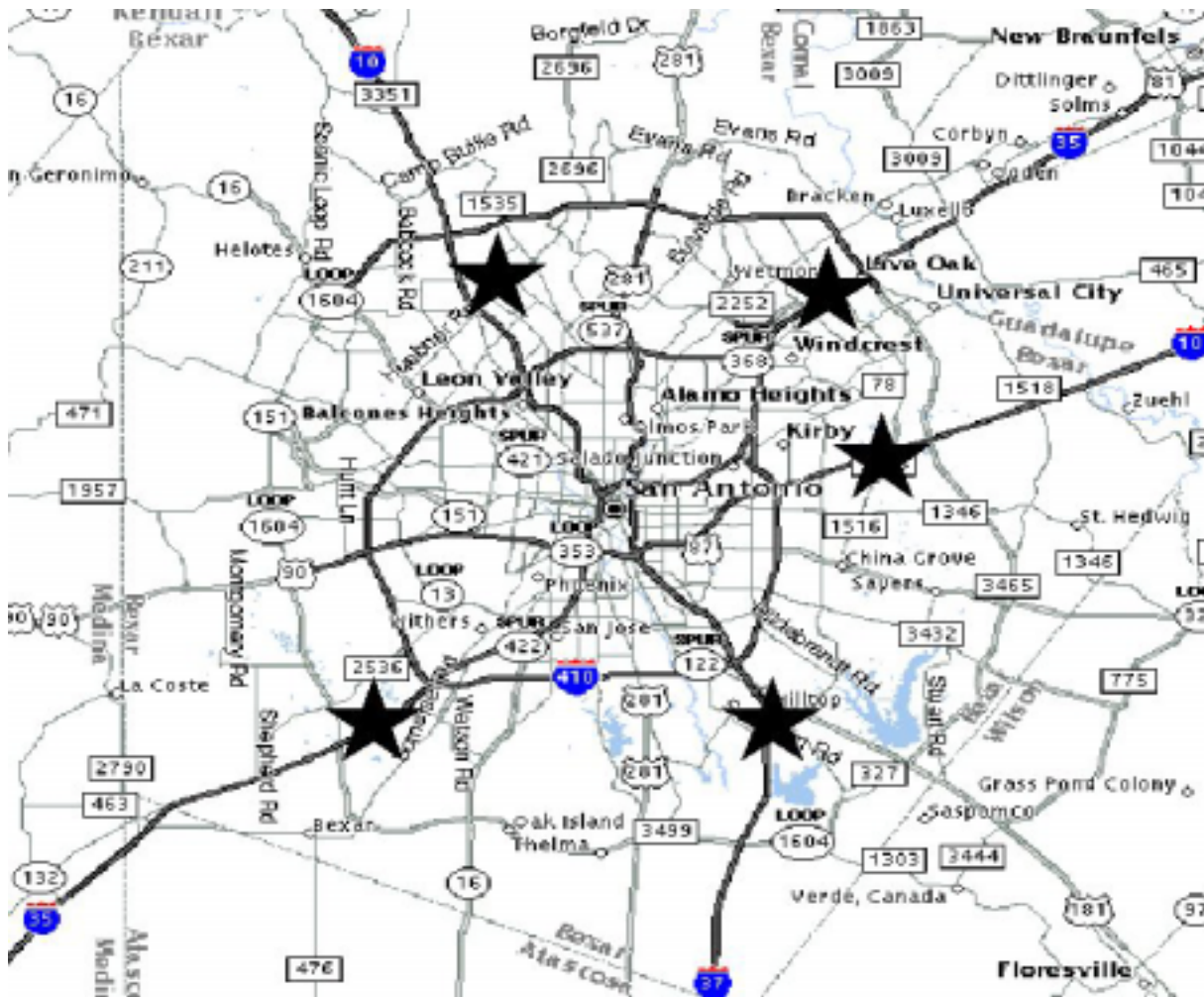


Figure 3. Proposed RWIS Locations; San Antonio, Texas

Transguide’s maintenance division has shown interest in this type of system and has indicated interest in raising funding for an RWIS system. Specific dollar amounts for maintenance costs of these systems are unknown. However, with the public relations people and the reputation Transguide has earned, it should not be hard for Transguide to raise and support this type of system.

Funding could possibly be shared between the maintenance division and the operations division. Transguide has shown interest in these systems for operational purposes as well, and might be willing to share some of the cost and responsibility between the two divisions.

Staffing

Personnel will be needed for the maintenance and operation of these systems. Transguide has indicated a willingness to devote the equivalent of 1.5 to 2 positions for this purpose. The duties that these personnel would take on would be add-on duties to what they are already assigned. Training of these personnel should be of high priority. A key in making a system like this work is to have good people running the system. Therefore, very thorough training programs should be implemented so that the RWIS is allowed to develop to its full potential. Transguide has conducted similar training programs and staffing problems should not be an issue.

Partnerships

Public/private partnerships are one area that Transguide has little experience. Typically RWIS have seen efforts to develop partnerships between public and private agencies to aid in the success of these systems. Transguide does have minimal experience with partnerships and the author believes that implementing this system would be a good opportunity for Transguide to expand on their partnership experience.

For private agencies to buy into the idea of RWIS systems, they need to be able to see the benefits and know that profits will be seen. Transguide has a successful public relations program and has seen success in selling their ideas to public agencies. Therefore, it is not foreseen that Transguide will have problems getting private sector firms involved in this type of operation.

Expandability, Transferability, and Compatibility

In the review of the literature, very few RWIS systems were found to exist in the states neighboring Texas. For this reason, incompatibility should not be a problem. Most of the projects reviewed from other areas have chosen to install SSI systems for weather prediction purposes. Since this geographical area is new to these types of weather prediction systems, Transguide should strive for compatibility with regions and states that have already seen successful implementation of these types of systems. The most common system used throughout the United States seems to be the Surface System, Inc. weather stations.

Of the four criteria developed, San Antonio shows strong potential in the areas of funding and staffing. Transguide has minimal experience with partnerships, and therefore this criteria was a little weak. However, as stated above it is not foreseen that there will be problems getting private sector firms involved due to Transguide's strong reputation. The issue of compatibility of components is virtually non-existent in this area due to the fact that San Antonio would be one of the first cities in its region to implement such a program. With this said, the author believes that San Antonio would be a good candidate for implementation of an RWIS system.

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**OPENING HOV LANES TO GENERAL TRAFFIC DURING MAJOR
INCIDENTS AND SEVERE WEATHER CONDITIONS**

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ABSTRACT

A restriction in roadway capacity results in long queues, long motorist delays, greater emissions and a higher potential for secondary accidents. In order to avoid the impacts of major incidents or severe weather conditions, many areas containing HOV facilities have implemented HOV diversion strategies in their incident management strategies. Some locations use various criteria for determining if the HOV lane should be opened for general traffic use. Often the officer on the scene is responsible for the decision of opening the HOV lane to single occupant vehicles. Once a decision is made to open the HOV lane to general traffic a diversion plan must be followed and instructions must be clearly expressed to the drivers.

The objectives of this research were to:

- Establish current practices for diverting general traffic into HOV lanes during major incidents or severe weather conditions.
- Develop a set of general criteria for HOV facilities where the HOV lane should be opened to accommodate all traffic.
- Develop guidelines for a typical diversion plan for opening HOV lanes to the general traffic.
- Apply guidelines to a specific location.

Through a literature review and a series of interviews with six agencies that operate HOV facilities recommended criteria was developed to determine when the HOV lane should be opened to general traffic. A volume-capacity ratio of 0.7, which is a level of service D according to the 1997 Highway Capacity Manual, is a reasonable threshold value that should exist before the general traffic is diverted to the HOV lane. Once an incident occurs, the goal of the diversion plan is to maintain a volume-capacity ratio of 0.95 throughout the duration of the incident. A freeway can theoretically sustain a volume-capacity ratio of 1.0. However, the volume-capacity ratio of 0.95 was chosen because 1.0 is potentially unstable and anything above this value could cause the freeway to breakdown. The threshold value for reduction in capacity for the freeway is suggested by the author to be 50 percent for an estimated time to clear the incident of 1 hour. Fifty percent was chosen because a single lane blockage on a three-lane freeway results in a reduction of fifty percent of the capacity. A duration of the incident of 1 hour was chosen because the average incident takes around 45 minutes to clear. If the capacity is reduced by 50 percent on a freeway for more than an hour with a volume-capacity ratio of 0.7 then the alternative routes must be able to handle 33 percent of the traffic on the freeway in order to maintain the desired volume-capacity ratio of 0.95. If the alternative routes off of the freeway and the remaining mainlanes cannot handle this amount of traffic then the HOV lane should be opened.

These criteria should be used by the response team to assess the situation and determine if lifting the HOV lane restrictions is warranted. The response team would be in communication with the traffic management center in order to receive operating conditions on the mainlanes and HOV lanes. The implementation plan used in the HOV diversion strategy would include the following issues.

- Identification of the corridor
- Formation of agency partnerships
- Determination of alternative routes
- Defining HOV diversion criteria
- Development of signing and other traffic devices
- Coordination with the media
- Final implementation

These issues provide the framework of a typical HOV diversion implementation plan. They would need to be modified for specific locations and situations. The criteria and diversion plan is applied to I-270 in Montgomery County, Maryland.

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INTRODUCTION

Many states such as Maryland, Minnesota and Texas, Virginia and Washington divert general traffic to the High Occupancy Vehicle (HOV) lane in order to by-pass a major incident during peak and off-peak hours. The diversion process is dependent on the configuration of the HOV lane, severity of the incident and agency policy. A restriction in roadway capacity results in long queues, long motorist delays, greater emissions and a higher potential for secondary accidents. In order to avoid the impacts of major incidents or severe weather conditions, many areas containing HOV facilities have implemented HOV diversion strategies in their incident management strategies. Some locations use various criteria for determining if the HOV lane should be opened for general traffic use. Often the officer on the scene is responsible for the decision of opening the HOV lane to single occupant vehicles (*I*). Once a decision is made to open the HOV lane to general traffic a diversion plan must be followed and instructions must be clearly expressed to the drivers.

Opening the HOV lane to general traffic is a very politically volatile issue. HOV users expect a certain level of service which would be disrupted by the adding general traffic. General traffic users also expect efficient movement of vehicles on the mainlanes which sometimes requires adding the HOV lane to increase the capacity of the freeway. Criteria boundaries of when opening the HOV lanes to general traffic should be allowed has not been clearly defined in most locations. Specific criteria used to decide if opening the HOV lane to general traffic is warranted is presented in this paper along with a typical diversion plan used to divert traffic. The goal of this strategy is to improve the overall operation of the freeway. The investigation included an examination of the criteria used to open HOV lanes to general traffic and the actions taken by agencies during severe weather conditions or major incidents. This research provided a typical diversion plan that can be applied to an HOV facility. The issues discussed in the diversion plan included how drivers know to divert to the HOV lane; the ability of a driver to reach a desired exit ramp; the length of time or distance that the driver will be allowed to travel in the HOV lane as a single occupant; and the reason for diversion. The diversion plan also included a discussion of possible ITS technologies that can be used in the plan. However, no specific technology is endorsed because the general plan must be altered for the specific technologies that are available for each facility.

Objectives

The objectives of this research were to:

- Establish current practices for diverting general traffic into HOV lanes during major incidents or severe weather conditions.
- Develop a set of general criteria for HOV facilities where the HOV lane should be opened to accommodate all traffic.
- Develop guidelines for a typical diversion plan for opening HOV lanes to the general traffic.
- Apply guidelines to a specific location.

Scope

The paper will include only freeway applications of HOV lane diversion plans during unplanned events such as major incidents or severe weather conditions. The HOV facilities are located in major metropolitan areas. Six agencies responsible for incident management on a variety of freeway HOV facilities were selected for interviews. Through the interview process the analyst received detailed information of each agency's diversion plan. The findings were used to determine a set of general criteria of when to open an HOV lane to general traffic and to develop a typical diversion plan.

Report Organization

The report is divided into nine sections. The first section includes the objectives and study approach of the research project. The study methodology which was used during the research is explained in the next section. The study methodology includes information on the literature review, data collection methods and how the results were analyzed. The background section of the report includes a discussion of general HOV terminology and the importance of incident management.

The results of the survey questions asked of each agency are provided in the fourth section. General information on each HOV facility analyzed such as occupancy level, type of facility and time of operation is given in this section. The study results will also provide the agency policies on opening HOV lanes to general traffic during severe incidents and the HOV facility's diversion strategy. The fifth section includes the issues involved in implementing an HOV diversion plan. The developed general criteria used to determine the opening of HOV lanes to general traffic is included in the sixth section. The next section provides a set of guidelines for a typical HOV diversion plan. The developed diversion strategy for an actual HOV facility is described in the eighth section of the report. The final conclusions which include a discussion of the importance of developing criteria for decision makers and the public acceptance of a decision are included in the ninth section of the report.

STUDY METHODOLOGY

Literature Review

A literature review was performed to identify a minimum of five HOV facilities to be studied and analyzed. Information on pertinent HOV lane characteristics including time of operation, occupancy level, type of system, incident management and diversion policies and any safety and operational issues associated with such plans were obtained. Also, the literature review provided information on HOV terminology and the importance of incident management. The information gathered in the literature review search is presented in the Background and Study Results sections of the report.

Data Collection

The data collection task of the research consisted of questioning six transportation agencies to determine current practices of diverting general traffic to HOV lanes during major incidents or severe weather conditions. The questioning process of the transportation officials was guided by a series of questions that are shown in the Appendix. The individuals that were contacted have a direct connection to the operation of the incident management strategies on the HOV facilities. The agency officials were asked a variety of questions that were used to determine the policy on opening HOV lanes to general traffic, criteria used to determine when the HOV lanes should be opened and the strategies used to carry it out. The agency officials were also asked to describe the coordination between all of the agencies involved in the incident management. The following table provides a list of individuals contacted and the organization with which they are associated.

Table 1. Questionnaire Contacts

Contact	Organization
John Gaynor	Texas Department of Transportation, Houston
Mahesh Kuimil	Dallas Area Rapid Transit
Joel Katz	Minnesota Department of Transportation
Jimmy Chu	Virginia Department of Transportation
Michelle Hoffman, Saed Rahwanji	Maryland State Highway Administration
Les Jacobson	Washington Department of Transportation

Data Analysis and Application

The information presented in the Study Results section of the report was examined to determine the incident management plans used by various agencies. A list of criteria that determines when an HOV lane should be opened to general traffic was gathered from the agency interviews. A level of importance of each criterion was determined from interviews and then included in a general list of criteria of when to allow general traffic to travel on the designated HOV lanes. From the agency interviews the recommended implementation strategy was developed. A case study for the proposed guidelines and diversion plan is presented to illustrate the proposed process.

BACKGROUND

The concept of diverting general traffic to HOV lanes involves two aspects of transportation: incident management and HOV system operations. The following sections describe these two areas.

Incident Management

The public and transportation officials have recognized the need for well-developed incident management strategies in order to reduce congestion on the roadways. The capacity on a three lane freeway can be reduced by 50 percent when an incident blocks only one lane. The incident also has a significant effect on opposing traffic because of rubbernecking. In a one hour period during an incident, the traffic back-up can reach 8.5 miles when the traffic flow is near capacity. Observations in Los Angeles indicated that during off-peak travel periods each minute of incident duration results in 4 to 5 minutes of delay (2).

Incident management is a process to reduce the time to detect an incident, initiate an appropriate response, clear the incident, communicate appropriate information to motorists and to divert and manage traffic until the roadway returns to full capacity. Effective incident management involves a coordinated and cooperative approach among all agencies. Agencies that may be involved in an incident management team are state departments of transportation, transit agencies, police and fire departments, emergency medical services and towing companies. The benefits of a sound incident management program includes reduced business costs associated with delays, fewer secondary incidents and improved air quality due to lower vehicle emissions (3). An incident can be defined as an accident, disabled vehicle, debris on the roadway and other random events that reduce the capacity of a roadway. The National Highway Traffic Safety Administration defines a major freeway incident to include motor vehicle crashes that involve serious fatalities and serious injury, motor vehicles on fire, crashes where cargo is spilled, overturned vehicles, downed power lines or structural

failures (4). Unpredictable timing and location of incidents are the main reasons they are difficult to manage. Most travelers plan for peak hour congestion conditions but delays due to incidents cannot be foreseen. Due to the increase in traffic volumes, the frequency and impacts of incidents have also become higher. Secondary accidents are also a concern in incident management (2).

Traffic management during an incident is extremely important. Proper traffic management will reduce the impact of the incident and provide a safer environment for motorists and responders. In a situation where diversion from the freeway is necessary, inadequate traffic management will result in lost motorists, additional surface street congestion and more secondary accidents. Traffic accidents require that the responders, police, service patrols and private wreckers are equipped with proper traffic control devices and the traffic management strategies are well planned and understood. Roll up signs, cones and other portable devices should be standard equipment for first response teams, those first arriving on the scene of an incident (2).

Motorist information is also a vital aspect of an incident management plan. A well informed motorist can make a travel decision based on the given information. The motorist can make the decision to divert around or stay away from an incident site, delay or change the time of a trip or even change travel modes. Variable message signs (VMSs), highway advisory radio, radio and television reports and traffic reporting services are valuable in advising motorists of incidents and other traffic related situations (2).

Many strategies are used in incident management plans. Some agencies have used HOV lanes in their incident management plans as a diversion strategy. Agencies in Dallas, Houston, Maryland, Virginia and Washington, among others use the HOV lane as a diversion route for vehicles to by-pass a major incident (1,5,6). The diversion process depends on agency policy, HOV lane configuration and the severity of the incident (1).

HOV Lanes Description

HOV facilities are being used in many areas to lessen the growing problem of traffic congestion. Many areas are faced with the dilemma that the projected travel demands cannot be reasonably served at current occupancy levels. Therefore, the goal of encouraging travelers to use HOV facilities is to increase the average person-carrying capacity of the roadway without being forced to construct new general purpose lanes. The characteristics of an HOV lane include occupancy level, type of facility and time of operation. Each of these characteristics is important to the implementation of a diversion strategy. The type of facility determines the accessibility of the general traffic to the HOV lane while by-passing an accident (7). Three types of facilities are discussed in the following sections: concurrent flow lanes, reversible flow lanes and contraflow lanes.

Concurrent HOV Flow Lanes

A concurrent flow lane operates in the direction of adjacent general purpose lanes and is designed for use by HOV's during all or a portion of the day. The lane is normally separated from general traffic by a double stripe or a buffer area. Concurrent lanes are usually located on the inside lane but they may also be positioned on the outside lane. Entry to the lane may be limited to specific access points or allowed anywhere on the facility. The concurrent flow lane is the most common HOV lane type because it is less expensive to implement than the other types. However, the occupancy level on the concurrent flow lane is much more difficult to enforce (8). Figure 1 shows an example of a concurrent lane facility.



Figure 1. Concurrent HOV Flow Lane Along I-405 in Seattle, Washington (9).



Figure 2. Reversible HOV Flow Lane in the Center of I-394 in Minneapolis (10).

Reversible HOV Flow Lanes

Reversible HOV lanes allow the direction of traffic flow to be changed at different times of the day. The inbound traffic is served during the morning peak while the outbound traffic travels in the lane during the evening peak. Reversible lanes are separated from the general purpose lanes by concrete barriers and access is limited by gates and pylons. Figure 2 shows an example of a reversible flow lane (8).

Contraflow HOV Flow Lanes

Contraflow lanes are lanes taken in the off-peak direction of travel and designated for exclusive use by HOVs traveling in the peak direction. The lane is separated from the off-peak direction general purpose travel lanes by some type of changeable treatment such as a moveable concrete barrier, plastic posts or pylons. Contraflow lanes are typically operated only during the peak period. They are only used when a significant directional distribution exists on a facility and there is available capacity in the non-peak direction. Figure 3 provides an example of a contraflow lane (11).



Figure 3. Contraflow HOV Lane Along I-93 in Boston, Massachusetts (12)

SURVEY RESULTS

In order to determine specific criteria and develop a typical diversion plan, six agencies responsible for operations or incident management on HOV facilities were interviewed by telephone. The characteristics of each HOV facility were determined. The characteristics included type of facility, occupancy level, time of operation and number of general purpose lanes. Diversion policies used by these agencies were determined as well as any criteria used to determine when the HOV lane restrictions should be lifted. The agencies interviewed are listed in alphabetical order. Summary tables of facility characteristics and diversion policies are provided at the end of this section.

Dallas, Texas

Facility Characteristics

The East R.L. Thornton Freeway Contraflow HOV (I-30) lane opened and began operation in Dallas in October 1991. The lane is open to vehicles with an occupancy level of 2 or more between 6 a.m. to 9 a.m. and 4 p.m. to 7 p.m. The inside freeway lane in the off-peak direction of travel is dedicated for HOVs in the peak direction. Traffic is separated by a moveable concrete barrier. The reversal process which involves changing and constructing a temporary barricade of pylons takes approximately two hours. There are no emergency access gates along the length of the barrier. The I-30 HOV lane is 8.4 kilometers in the morning

(westbound) and 5.3 kilometers in the evening (eastbound). The number of general purpose lanes is three (5).

The two concurrent HOV facilities operating in Dallas are I-35E and I-635. These lanes are open to vehicles with at least two occupants 24 hours a day and are separated from the general purpose lanes by a double-wide stripe. The lanes designate two entrances and two exits. The 24 hour operating time was determined based on the belief that motorists would be less confused and mainlane off-peak volumes are not heavy enough to require extra capacity. I-635 is one of the busiest freeways in the United States and is the most used HOV lane in Texas. Both freeway facilities have three general-purpose lanes in each direction. I-35E and I-635 have been very successful projects for Dallas. The violation rates for the two HOV facilities is 6 percent which is well below the accepted rate of 15 percent (5).

Diversion Policies

The HOV system in Dallas is operated by the Dallas Area Rapid Transit (DART). DART allows the diversion of general traffic to HOV lanes under severely congested conditions. The desire of DART is to maintain the credibility of the HOV lane and only use the HOV lane as a last resort in an incident management plan. The respondents will attempt to use the shoulders or exit ramps before diverting traffic onto the HOV lane. HOV lane diversion only occurs an average of five to six times a year on I-635 and I-35E. The agencies responsible for incident management are DART and the local police. Incident detection is determined by cameras placed at one-mile spacings along each freeway and surveillance performed by the Mobility Assistance Patrol, Courtesy Patrol, transit police and local police. The transit police and local police make the decision to open the HOV lane to the general traffic. DART does not have set criteria for the respondents to follow to determine when the lane should be opened. However, it is understood that the single occupant vehicles should not travel on the HOV lane unless the situation is unavoidable. Variable message signs, cones, flags and media announcements are used to give motorists the proper instructions as to diverting on the HOV lane. Once the single occupant vehicle (SOV) by-passes the incident on the I-635 or I-35E HOV lane the motorist is expected to merge back onto the general-purpose lane. Directional signs are not used to direct SOVs back on to the general travel lanes and occupancy level is once again enforced at a reasonable distance from the incident (5).

If a major incident significantly blocks the I-30 mainlanes, the superintendent of the DART crew stationed on site recommends to DART administrators whether or not the HOV lane should be opened to general traffic. Since there are not emergency access gates that can be opened on the non-peak side, the contraflow facility cannot be reversed to divert non-peak mainlane traffic. Also, only the barrier transfer machine can move the barrier to allow non-peak traffic into the HOV lane. According to officials the HOV lane diversion has only occurred a couple of times on I-30 (1).

Houston, Texas

Facility Characteristics

Five barrier separated HOV lanes with an occupancy level of two or more are operated by the Houston Metropolitan Transit Authority (METRO) and the Texas Department of Transportation (TxDOT). Each facility is a one-lane facility except for a short two-lane section on US 290. I-45N, I-45S, US 59S, and US 290 allow inbound vehicles to travel between 5 a.m. and 11 a.m. and outbound traffic between 2 p.m. and 8 p.m. during the weekdays. The I-45S lane is also open to inbound HOV traffic from 3 p.m. to 9 p.m. on weekends in the summer (1).

The I-10 HOV lane is one of three congestion pricing demonstration projects currently functioning in the United States. The I-10 HOV lane requires a fixed toll for vehicles with occupancy levels of two or more during specified times of the day and are billed through transponders. The facility is open between 5 a.m.

and 6:45 a.m. and from 8 a.m. to 11 a.m. Vehicles with an occupancy level of three or more travel the HOV lane for free between 6:45 a.m. and 8 a.m. while vehicles with only two occupants must pay a toll. The outbound traffic travels on the HOV lane between 2 p.m. and 5 p.m. and 6 p.m. to 8 p.m. Vehicles are tolled in the same manner as inbound HOVs between 5 p.m. and 6 p.m. Outbound vehicles with an occupancy of 2 or more are allowed to travel on Saturdays between 5 a.m. and 8 p.m. while on Sundays the same restrictions are used for the inbound traffic (1,13).

Diversion Policies

Houston coordinates the ITS infrastructure through the TranStar traffic management center. TranStar is jointly operated by Houston METRO, TxDOT, Harris County and the City of Houston. A network of loop detectors, Automated Vehicle Identification (AVI) readers, VMSs, Closed Circuit Television (CCTV) cameras and overhead lane control signals are used to monitor the traffic situation. The spacing of the overhead lane control signals is approximately two miles apart throughout the HOV network (13).

HOV lane diversion is implemented approximately ten times per year. Houston does not have a specific set of criteria that are followed to make a decision to lift the HOV restrictions. METRO's police force can decide to open the HOV lane to SOVs if the major incident causes extreme congestion and there is not an available diversion route for traffic. VMSs upstream of the incident provide motorists with diversion information. The messages are changed by METRO officers stationed at TranStar. The media is also used extensively to give the public information on the traffic situation (13).

Maryland

Facility Characteristics

Two concurrent HOV lanes are operated by the Maryland State Highway Administration (SHA) along I-270. The lanes are separated from the general-purpose lanes by a two-foot buffer. Vehicles with an occupancy of two or greater are allowed access to the HOV lanes between 6 a.m. and 9 a.m. for southbound traffic and from 3:30 p.m. to 6:30 p.m. for the northbound direction. All traffic is allowed to use the lanes outside of these hours (1).



Figure 4. Concurrent HOV Lane Along I-270 in Maryland (14).

Diversion Policies

The incident management responsibilities are coordinated through the Maryland SHA, state police and Montgomery County. Maryland does allow the diversion of general traffic for major incidents and severe weather but there is no predetermined criteria as when to lower the restrictions on the HOV lane. It depends generally on the extent of the incident, time of the incident and the length of the queue. A network of VMSs and highway advisory radio along with media reports, coordinated through the Statewide Operations Center, informs the drivers that restrictions will be lifted on the HOV lanes due to an incident on the mainlanes. Once the restrictions on the HOV lane are lifted then the lane remains open to general traffic for the duration of the peak period because it is difficult to clear the lanes of SOVs after diversion. Field personnel is required to set up arrow boards and direct the diversion process in order to ensure drivers are aware of the situation and are clearly told the proper action (6).

Minnesota

Facility Characteristics

The HOV facilities in Minneapolis-St. Paul, Minnesota opened in 1992. Currently, three facilities operate within the freeway network around the Twin Cities. I-394 west of Highway 100 is a concurrent facility that is reserved for HOVs with an occupancy level of two or more between 6 a.m. and 9 a.m. for eastbound traffic and 3 p.m. to 6 p.m. for westbound traffic. This section of I-394 has two general-purpose lanes and two concurrent HOV lanes. The section of I-394 east of Highway 100 is a reversible, barrier separated lane that is open to eastbound HOVs between 6 a.m. and 1 p.m. and westbound traffic between 2 p.m. and midnight. This section of I-394 consists of three general-purpose lanes and two reversible lanes in the middle of the freeway. The third HOV facility on I-35W is a concurrent facility located between Highway 13 and I-494 and is available to HOVs between 6 a.m. and 9 a.m. and 3 p.m. and 6 p.m in each direction. I-35W has three general-purpose lanes and two HOV lanes located on the inside of the freeway. SOVs are allowed to use the concurrent facilities while restrictions are not in place (15).

Diversion Policies

The Minnesota Department of Transportation is responsible for the operation of HOV facilities. The three HOV facilities operate within a surveillance network composed of loop detectors, CCTVs, regular police patrol and citizen calls. The cameras on I-35W and I-394 west of Highway 100 are spaced at one-mile intervals while the cameras placed on I-394 east of Highway 100 are spaced at one-half miles because of the locations of bridges throughout the corridor. The loop detectors measure the speed and levels of congestion on each facility. According to officials the most important and reliable indicators of the traffic situation are calls from motorists. Motorist information is given to drivers by VMSs, highway advisory radio and through the media (15).

The state police responding to the incident have the authority to implement a diversion strategy. However, there is not a set policy regarding diversion of general traffic to HOV lanes. To date, the lanes have not been used for diversion because congestion has generally not been considered high enough to warrant such a strategy. The policy is that the Minnesota Department of Transportation has made a commitment to HOV users that the HOV lane will be available during specified operating hours. The reliability of the HOV facility is the incentive for drivers to use HOV lanes (15).

Seattle, Washington

Facility Characteristics

The Washington Department of Transportation (WSDOT) operates a number of different types of HOV facilities. Concurrent facilities operate on I-405, SR 167 and SR 520 while reversible and concurrent HOV lanes operate on I-5 and I-90. All of the existing I-405 lanes have an occupancy definition of two or greater which is enforced 24 hours a day. SR 167 contains approximately eight HOV lane miles that are open to traffic 24 hours a day with an occupancy greater than one between South Grady Way and 84th Avenue South. Three more HOV projects are planned for the SR 167 corridor that will extend the HOV facility south to Puyallup. A shoulder lane on westbound SR 520 requires vehicles with three or more occupants. SR 520 is the only HOV lane on state highways with an occupancy level of three or more that is enforced 24 hours a day. The existing HOV lane on I-90 includes a reversible HOV roadway with an occupancy requirement of two or more between Seattle and Bellevue and 24-hour HOV lanes on the westbound and eastbound mainline between Bellevue and Issaquah (9).



Figure 5. Reversible HOV Lane Along I-5 in Seattle, Washington (9).

The I-5 reversible lanes are open to HOVs with two or more occupants between 5 a.m. and 8:30 a.m. and from 12 p.m. to 4 a.m. in the peak direction. The number of lanes provided by the facility varies from one to four. Both facilities contain concurrent sections that are open to HOVs with an occupancy level of two or more 24 hours a day (9).

Diversion Policies

The traffic conditions must prove to be extremely severe if the HOV lane is opened to SOVs. The WSDOT try to provide efficient movement on the HOV lanes in order to satisfy carpoolers and bus riders. The credibility of the HOV lanes with the public is a priority with WSDOT. Therefore, lifting the restrictions on the HOV lane does not occur very often (16).



Figure 6. Concurrent HOV Lane Along I-5 in Seattle, Washington(9).

The state police have the authority to open the HOV lane to general traffic when a major incident occurs. The state police do not have any type of set criteria to follow in order to make a decision. However, the decision generally depends on the severity of the incident, time of day and the availability of diversion routes other than the HOV lane. A network of VMSs and portable signs, along with police officers will direct the traffic around the incident. The time of day that the incident occurs is an extremely important factor to the decision of opening the HOV lane. WSDOT will normally not open the HOV lane to SOVs during the peak period because they do not want to cause any delay to bus riders (16).

Virginia

Facility Characteristics

The Shirley Highway HOV lanes serve commuters traveling to and from Washington D.C. in Northern Virginia. The HOV lane is part of I-95 and I-395 and has four general-purpose lanes in each direction. The facility is a two-lane, reversible, barrier-separated system. The northbound direction of the Shirley Highway is open to HOVs from 6 a.m. to 9 a.m. on Monday through Thursdays. It is open to all general traffic from 9 a.m. to 11 a.m. and 10 p.m. to 6 a.m. In the southbound direction, the HOV lane is open to HOVs from 3:30 p.m. to 6 p.m. and to all traffic from 1 p.m. to 3:30 p.m. and between 6 p.m. and 8 p.m. The schedule on Fridays changes to allowing HOVs in the southbound to travel on the HOV lanes between 12 p.m. and 6 p.m. The lanes are opened to all southbound traffic from 6 p.m. on Friday to 8 a.m. on Sunday and then reopened to all northbound traffic from 10 a.m. Sunday to 6 a.m. Monday (1,17).

Diversion Policies

The Virginia Department of Transportation (VDOT) and the state and local police are responsible for incident management on the Shirley Highway. Diverting general traffic to the HOV lanes has been a very successful and popular idea with the public and local media. It was estimated that the decision to divert traffic onto the HOV lane occurs approximately 10 times per year. The decision is made jointly between the state police on the scene of the incident and VDOT. The HOV lane volumes are so high that VDOT does not want to allow general traffic to divert to the HOV lane often (18). Furthermore, VDOT has implemented a policy that says if an incident should occur in the non-peak direction, non-peak traffic will not be diverted to the HOV lane (1).

The criteria that are used to determine if the HOV lane should be opened to general traffic relates to the time it takes to clear the incident and the percentage of reduced capacity caused by the incident. If the operation of clearing a major incident lasts longer than two hours then the restrictions on the HOV lane will be lifted. Also, when an incident blocks 50 percent of the mainlanes in the peak direction then traffic will be diverted to the HOV lane. VDOT maintains a network of VMSs to alert drivers of any changes in the HOV lane restrictions. The VMSs will inform the driver of no restriction if the HOV lane is opened to general traffic. The restriction will last until the end of the peak period. Weather has rarely caused the opening of HOV lanes to general traffic. Only in the case of an extremely severe snowstorm where several feet of snow cover the freeway would VDOT consider lifting the restrictions on the HOV lanes. However, this situation has rarely occurs (17).

Table 2. Summary of Facility Characteristics

Location	Facility	Type	Occupancy	Time of Operation
Dallas, Texas	I-30	1 lane; contraflow	2+	peak hours in peak direction
	I-35E, I-635	1 lane; concurrent	2+	24 hour
Houston, Texas	I-45N I-45S US59S US290	1 lane; reversible, barrier separated (US 290 includes a short two-way section)	2+	Peak hours in peak direction; Weekends on I-45S
	I-10	1 lane; reversible, barrier separated (congestion pricing project)	2+	Peak hours in peak direction; outbound on Saturdays; inbound on Sundays
			Toll for 2+; free for 3+	6:45. to 8 a.m. and 5 to 6 p.m.
Maryland	I-270	1 lane; concurrent; buffer	2+; SOVs other times	Peak hours in peak direction
Minneapolis-St. Paul, Minnesota	I-394	East of HW 100-1 lane; reversible, barrier separated	2+	Peak hours in peak direction
		West of HW 100-1 lane; concurrent	2+; SOVs other times	Peak hours in peak direction
	I-35W	1 lane; concurrent	2+; SOVs other times	Peak hours in peak direction

Table 2. Continued

Location	Facility	Type	Occupancy	Time of Operation
Seattle, Washington	I-5N, I-5S	1 lane; concurrent	2+	24 hours
	I-5N	1 to 4 lanes with ramps; reversible; barrier separated	2+	Peak hours in peak direction
	I-90	2 lanes; reversible, barrier separated	2+	24 hours except for reversal periods
		1 lane; concurrent	2+	24 hours
	SR 167	1 lane; concurrent	2+	24 hours
	SR 520	WB shoulder lane; concurrent	3+	24 hours
	I-405	1 lane; concurrent	2+	24 hours
Virginia	Shirley Highway	2 lane; reversible, barrier separated	2+	Peak hours in peak direction

Table 3. Summary of Facility Diversion Policies

Location	Agencies Involved	Criteria Used to Divert	Motorist Information Techniques	Surveillance Techniques
Dallas, Texas	DART	No specific criteria	VMSs, cones, flags and media announcements	loop detectors, cameras, Courtesy Patrol, citizen reports
Houston, Texas	Metro, TxDOT, Harris County and City of Houston	No specific criteria	VMSs, overhead lane control signals, media announcements	loop detectors, cameras, AVI, police patrol, citizen reports
Maryland	Maryland SHA, state police and Montgomery County	No specific criteria	VMSs, highway advisory radio and media announcements	loop detectors, cameras, police patrol, citizen reports
Minneapolis-St. Paul Minnesota	Minnesota DOT, state and local police	No specific criteria	VMSs, highway advisory radio and media announcements	loop detectors, cameras, police patrol, citizen reports,
Seattle, Washington	Washington DOT, state police	No specific criteria	VMSs, portable signs, police direction	loop detectors, cameras, police patrol, citizen reports
Virginia	Virginia DOT, state and local police	50 percent of mainlanes closed and time to clear incident more than 2 hours	VMSs, highway advisory radio, police direction	cameras, police patrol, citizen reports

ISSUES TO IMPLEMENTING AN HOV DIVERSION PLAN

Agency interviews and the literature review identified a number of barriers to implementing an HOV diversion plan. These include agency policy, motorist information, public acceptance and development of HOV lane diversion criteria.

Agency Policy

A problem must exist on the freeway before a diversion plan that would divert general traffic onto the HOV lane is implemented. The problems that might exist are heavy volumes on the freeway or a lack of alternate routes for mainlane diversion during incidents (*I*). It is important to understand agency policies on lifting the restrictions on HOV lanes during operating hours. Minnesota has a very strict policy to keep the HOV operating hours. Due to relatively low congestion levels, most corridors can handle the daily traffic load. As discussed in the Study Results section of the paper, Minnesota is not opposed to opening the HOV lane to general traffic during extremely severe situations but the congestion levels have never been high enough to warrant such an action. However, due to heavy congestion in Virginia, VDOT's policy allows the opening of the HOV lane approximately ten times per year. Similarly, due to the high traffic volumes on the Dallas freeways, DART allows opening HOV lanes approximately five to six times per year. The agency policies are very dependant upon the mainlane congestion levels of the freeways. Policy also depends on the traffic load on the HOV lane.

Motorist Confusion

Some agencies choose to operate the concurrent flow lanes 24 hours a day and do not allow general traffic on HOV lanes outside of peak periods. The reason for this policy is to minimize motorist confusion as to when the HOV restrictions are in place. Agencies such as DART where the HOV lanes are relatively new and might be unfamiliar to drivers are afraid too much HOV lane information might cause confusion. Also, the 24 hour operation time protects infrequent users from misunderstanding the HOV operating periods.

Areas with peak period operation are also concerned with the driver understanding the instructions to divert to the HOV lane. Clear and concise information must be presented to reduce any confusion for the driver. A person who is accustomed to driving in the mainlanes might not be familiar with the HOV lane. The following key pieces of information must be given to a driver in order to provide understanding during a diversion process.

- Reason for diversion;
- Length of time or distance that the motorist be allowed to continue to drive on the HOV lane;
- Ability to exit on the desired ramps for barrier separated facilities.

In order to implement a diversion strategy in areas with 24 hour a day or peak period operation, careful attention must be given to informing drivers of current situation. The driver must understand the steps that they should follow in order to avoid the incident or divert into the HOV lane.

Public Acceptance

HOV lanes were created to increase the travel time savings and provide vehicles with multiple occupants a less congested environment. Maintaining HOV credibility might mean operating a lane at a specific level of service or as in the case of Seattle, keeping the average HOV lane speed above 45 miles per hour. The users depend on the HOV lane to provide significant travel time savings. Otherwise, drivers would be discouraged from traveling the HOV lane and not see the benefit of carpooling.

If the HOV lane restrictions are lifted too often then the public may question the value of the lane. Negative public perception may lead to the abolishment of the HOV lane. Also, if restrictions are modified often, then

SOVs may become so used to traveling in the HOV lane that violations may increase and enforcement becomes difficult. The SOVs would also not see the benefit of carpooling if the occupancy level is lifted often.

Development of HOV Lane Diversion Criteria

None of the agencies except one interviewed for this paper had predetermined criteria used to decide if the HOV lane should be opened for general traffic during major incidents or severe weather. Virginia opens the HOV lane if an incident blocks 50 percent of the mainlanes in the peak direction and is expected to take two hours to clear. The majority of the agencies interviewed for this report give the responsibility of the decision to divert to the response team that arrive on the scene. However, the response team often consults with the traffic management center or the state department of transportation before making a decision. It is important for the officers on the scene to have a clear understanding of what type of conditions to look for before opening the HOV lane to general traffic. A general set of criteria given to the officers or incident management team would allow a decision to be made quickly and decisively.

The set of general criteria must be a list of what type of conditions should be analyzed before a decision is reached. Issues including the severity of the situation, time of day, impact on the mainlanes and availability of diversion routes. The severity of the impact on traffic would account for the percentage of the capacity reduced on the mainlanes and the time to clear the incident. The availability of alternative routes would involve using shoulders, ramps or available mainlanes to divert traffic. In order to maintain the credibility of the HOV lane, diversion to the HOV lane should only take place as a last option. The time of day would give an indication of how the current and expected traffic would be affected. Information on the current operating travel volumes on the HOV lane is important in order to determine the type of impact diverting traffic would have on the existing HOV traffic.

The criteria can be a set of guidelines for the response team so that an informed decision can be made. It must train the officers to know the road conditions that are vital in determining if HOV restrictions should be lifted. The decision will ultimately be a judgement call based on the situation of the specific location. Criteria cannot be developed for every situation and every location. Therefore, the experience and instinct of the officers on the scene plays an extremely important part in the decision to open the HOV lane to SOVs.

DEVELOPMENT OF GENERAL CRITERIA FOR DIVERSION TO THE HOV LANE

The following section contains guidelines developed by the author that could be used when determining if the restrictions on the HOV lane should be lifted during a severe situation. It is helpful for response teams to have a set of criteria of what they should look for in order to make a good decision. Also, a set of general criteria provides a level of consistency for each decision that is made to open the HOV lane. The criteria is considered general because it must be tailored to each location. As the interviews revealed, every situation is different and a set of general criteria is not able to account for each and every situation. These criteria include determining the severity of the incident, time of day, impact on the mainlane traffic and availability of alternative routes.

Severity of Situation

As was discussed in an earlier section, a major freeway incident includes downed power lines, infrastructure failures and crashes involving fatalities, vehicles on fire, spilled cargo, hazardous cargo and overturned vehicles. The severity of the incident determines the type of response team that is needed. A quick response is needed for any type of severe accident especially when a person's life is in jeopardy. A path needs to be cleared for the emergency response team. The officer on the scene or traffic management team must decide if diverting traffic to the HOV lane would clear a needed path for the response team. The first responsibility that the officer or incident management team has is the safety of the victims involved in the incident. The

weather situation can also make the conditions on the roadway dangerous. Weather conditions can cause severely congested conditions. It is important for the correct assessment of the accident or weather situation to be made immediately, before any action is taken.

The severity of the situation determines the length of time that is needed to clear the roadway for oncoming traffic. The time needed to clear the incident will provide a good estimation of the queue length caused by the situation. As was mentioned earlier, when one lane on a three lane freeway is blocked during an incident the resulting back-up grows at a rate of 8.5 miles per hour. Therefore, it is vital to make a quick decision in order to prevent severe congestion.

Time of Day

The time of day of the incident is extremely important to the decision of opening the HOV lane to SOVs. The peak period time is the most heavily traveled time of the day and when most commuters are most dependant on the operation of the system. Motorists use the HOV lanes because they have been convinced of the significant travel time savings. Citizens that use the transit system have also been told of the savings in travel time that they will receive. Opening the HOV facility to SOVs during peak periods must be carefully considered because of the detrimental effect that will occur to the credibility of the HOV lane if there is a significant loss in travel time savings.

Impact on Mainlane Traffic

An assessment of the impact that the incident is having on the mainlane traffic is important in determining if opening the HOV lane to general traffic is warranted. Developing performance measures that will assist the management team in determining the impact that the incident or weather situation has on the freeway mainlanes is very helpful in the decision making process. The primary impact that a major incident or severe weather conditions have on the freeway mainlanes is impeding traffic flow by reducing capacity. A reduced capacity can cause long queues and severe delays.

Only one of the agencies interviewed for this paper provides criteria to quantify the impact the incident or severe weather has on the mainlanes. Other agencies make a judgement call on the movement of traffic with no specific guidelines. The majority of the agencies decide to divert general traffic to the HOV lane if a major incident produces "prolonged congestion." A set of performance measures used as a guideline for incident management teams would provide consistency in the decision making process.

The response team should be in communication with the traffic management center to determine the correct course of action. A set of measures such as volume-capacity ratio, percentage of reduced capacity and estimated length to clear the accident should be used in the decision making process. The traffic management center could provide information on the volume-capacity ratio to the response team from surveillance cameras and loop detectors. The response team would be able to assess the seriousness of the situation and estimate the length of time needed to clear the accident and the percentage of the capacity reduced.

The author suggests that a certain level of traffic on the freeway be present before HOV diversion is considered. A volume-capacity ratio of 0.7, which is a level of service D according to the 1997 Highway Capacity Manual, is a reasonable threshold value that should exist before the general traffic is diverted to the HOV lane. Once an incident occurs, the goal of the diversion plan is to maintain a volume-capacity ratio of 0.95 throughout the duration of the incident. A freeway can theoretically sustain a volume-capacity ratio of 1.0. However, the volume-capacity ratio of 0.95 was chosen because 1.0 is potentially unstable and anything above this value could cause the freeway to breakdown. The threshold value for reduction in capacity for the freeway is suggested by the author to be 50 percent for an estimated time to clear the incident of 1 hour. Fifty percent was chosen because a single lane blockage on a three-lane freeway results in a reduction of fifty percent of the capacity (19). A duration of the incident of 1 hour was chosen because the

average incident takes around 45 minutes to clear (20). If the capacity is reduced by 50 percent on a freeway for more than an hour with a volume-capacity ratio of 0.7 then the alternative routes must be able to handle 33 percent of the traffic on the freeway in order to maintain the desired volume-capacity ratio of 0.95. If the alternative routes off of the freeway and the remaining mainlanes cannot handle this amount of traffic then the HOV lane should be opened.

Availability of Alternative Routes

Decision makers have a responsibility to the HOV users to maintain a facility that reduces the travel time for multi-occupant vehicles. A commitment has been made that the lane will be available during the specified operating hours. Reliability is part of the incentive for the HOV lanes. The lane becomes especially valuable to users when incidents or bad weather causes additional congestion on the general purpose lanes. Therefore, alternative routes other than the HOV lanes should be the first option in a diversion plan. In a diversion situation, the availability of shoulders and ramps should be determined before a decision to lowering the restrictions on the HOV lanes. The criteria presented in the previous section states that if the route off of the freeway and the remaining mainlanes is able to handle at least 33 percent of the freeway traffic then the HOV lane does not need to be opened to general traffic. Coordination with the traffic management center would give the response team the needed information to determine if the alternative routes can handle the desired traffic. It should be understood that the specific numbers could be changed to accommodate a specific location or traffic situation but the theory would remain the same.

GUIDELINES FOR TYPICAL HOV DIVERSION PLAN

The following section includes guidelines that should be followed when developing a typical HOV diversion plan. Several steps must be performed in developing a plan. These include identifying the corridor, forming agency partnerships, defining criteria used to make a decision to divert, determining alternate routes, developing effective signing and other traffic control devices, coordinating with the media and implementing the plan.

Identify the Corridor

The corridor that will be used in the diversion plan must be established. For plans using HOV lanes as a diversionary strategy, a facility must be located within the corridor. The corridor must also have a history of traffic problems due to severe accidents. The traffic problems may include congestion as well as secondary accidents due to the freeway conditions (21).

Form Agency Partnerships

It is vital to develop strong agency partnerships in any type of incident management plan. The plan presented in this report is not a full incident management plan but only one aspect of a plan. However, in order for any type of management plan to be successful it is important to establish good coordination between agencies. Only through strong partnerships can the diversion plan between jurisdictions run smoothly. Good communication and partnership must also be maintained between all of the groups that are involved in the incident management team. Often agencies such as the police, state department of transportation and transit agency work together to keep traffic running efficiently during an accident.

Determine Alternative Routes

Once the diversion corridor is identified it is important to develop a diversion route for the corridor. Developing a diversion route involves examining the major roadways in the area to determine which ones would be able to handle the traffic load from the freeway. Also, the location of where traffic should be diverted need to be analyzed. Areas with high incident rates will need to be taken into consideration during

the selection process. The current location of existing static or VMSs should be considered when determining a possible route.

The diversion routes should be considered before opening the HOV lane to general traffic. In order to maintain the credibility of the HOV lane it is important keep HOV users satisfied with the level of service on the HOV facility. Therefore, the HOV lane could be used if the traffic congestion is severe and planned diversion routes are not available.

Through communication with the traffic management center, the response team is able to determine the conditions of the diversion route. If the diversion route is considered heavily congested then the officers should consider lifting the restrictions of the HOV lane. Through loop detectors and cameras placed in strategic locations, the traffic management center can decide the impact the traffic from the freeway will have on the diversion route.

Define Criteria

Criteria that determine the warrants of opening an HOV lane to divert general traffic are important to establish. The response team must have an idea of what to look for in order to make a good decision on whether traffic should be diverted. A general set of criteria was presented in an earlier section. It is important to note that every accident situation is different so at times the traffic situation might not meet the general criteria but still should be diverted to the HOV lanes.

Development of Signing and Other Traffic Devices

Once the HOV lane is opened it is essential to inform the drivers of the traffic situation and the state of the HOV facility. The decision points on the freeway will include entrance points on the freeway, entrance points to the HOV lane, exit points to the freeway and exit points to the HOV lane. The signs should be in the form of VMSs in order to provide the motorist with enough information to make a decision. The message should be concise while still providing all of the information necessary. An example of a message that might be used would be as follows:

MAJOR ACCIDENT
1 MILE AHEAD
USE HOV LANE

Other technology that could be used to inform the motorists of a severe traffic situation is flashers. Flashers that are blinking would signify that traffic in the HOV lane is restricted. However, if the flashers are turned off then SOV traffic is allowed to enter the HOV lane. If drivers are familiar with the flashers, then they can be a very effective tool to provide information. Flashers would be located before the entrance to the HOV lane.

It is important to determine the policy if the HOV lanes will remain open for the duration of the operating period or if they will be available to all traffic while the accident is being cleared. For HOV facilities with 24 hour operating periods, the author suggests that the traffic only be diverted around the accident in the HOV lane and then return to their proper lane as soon as possible. However, so as not to create too much confusion, for facilities with specific operating periods it is suggested that once the restrictions are lifted then the facility be open for the duration of the peak period.

Coordination With Media

The media is a very useful tool in providing the public with information of the traffic situation. The incident management team should use the media to give information on freeway conditions. The media should be used in providing the following type of information.

- Level of congestion on the freeway
- Suggest alternate routes other than the freeway
- Inform the public if general traffic is being diverted to the HOV lane in order to avoid an accident location
- Inform the public of where they will be allowed to exit if they choose to divert to the HOV lane.

The television media or radio media could provide this information to motorists.

Final Implementation

The HOV lane diversion strategy is ready to be implemented once the necessary steps have been taken. Prior to implementing the diversion strategy, all message signs should be inspected in order to ensure that they will provide the correct information to the motorist. Once implemented, it would be beneficial to the safety and efficiency of the diversion plan if there was a continuous evaluation of the plan to ensure that the freeway operation improves once the HOV lane is opened. Also, an evaluation to conclude that the HOV lane is able to handle the extra traffic without limiting its effectiveness should be conducted. The cooperating agencies should perform the evaluation to ensure that the plan meets the proposed objectives. The main criteria in evaluating the implementation plan should be driver safety and the level of service of the mainlanes. A record of secondary incidents should be logged in order to determine how the implementation plan improved the safety of the motorists. The traffic management center should be able to determine the operating conditions of the general-purpose lanes and HOV lane from the information gained by the network of cameras and loop detectors. A third measure of the effectiveness of the plan is the extent of the public support of the decision. The satisfaction of the public is an extremely important factor in evaluating the implementation plan. A survey of users and non-users of the HOV facility should be performed to determine the public's opinion on whether the HOV lane should have been opened to general traffic.

CASE STUDY: I-270 IN MONTGOMERY COUNTY, MARYLAND

The guidelines presented in the previous section will be applied to the HOV facility on I-270 in Montgomery County, Maryland to illustrate how to implement a plan that allows SOVs to divert to the HOV lanes during major incidents and severe weather conditions. The area was selected because of available information on traffic patterns, lane configurations and surveillance equipment used to detect the traffic situation. The following figure shows the current HOV lane sequencing and intelligent transportation systems used on I-270.

Identify the Corridor

The need for a diversion plan on I-270 is obvious after examining the traffic patterns along the freeway. The Maryland SHA operates two concurrent HOV lanes that are restricted to vehicles of an occupancy of two or greater from 6 a.m. to 9 a.m. for southbound traffic and between 3:30 p.m. and 6:30 p.m. for the northbound direction. An incident would have a major impact on the traffic traveling on I-270. I-270 between the Capital Beltway and Clarksburg Road or MD 121 is a heavily traveled route for commuters. The following table includes information on traffic volumes on I-270 in the Rockville area.

Table 4. Traffic Volumes For I-270 at Montrose Road in Rockville, Maryland (14)

	AM Peak Period (6:00-9:00)	PM Peak Period (3:30-6:30)
Average Volume in the HOV Lane(Vehicles/Lane/Hour)	1225	1600
Average Volumes in the SOV Lanes(Vehicles/Lane/Hour)	2030	1985
Average # of People in the HOV Lane(People/Lane/Hour)	2735	3830
Average # of People in the SOV Lane(People/Lane/Hour)	2225	2035
Total Volume(Vehicles/Hour)	9360	9540

The average volumes in the SOV lanes are high enough to cause severe delays and long queues if impeded by a severe incident.

Agency Partnerships

The agencies involved in the HOV diversion plan would include the state police, county police and Maryland SHA. The local agencies will also be involved because some of the diversion routes selected include local roadways. The state agencies will be in close contact with the cities directly involved which are Rockville, Gaithersburg, Germantown and Clarksburg. Even though the state agencies will handle the majority of coordination for the diversion plan, it is important to establish good relationships with the local agencies in case any future problems occur that would require a closer partnership. The state agencies will be responsible for detecting the incident and operating the VMS in order to provide diversion information and providing details to the media that will assist motorists.

Determine Alternative Routes

The alternative routes used to avoid the incident should be considered before the HOV lane restrictions are lifted. The availability of the 14-foot shoulders along I-270 should be analyzed by the response team to determine if they would be adequate to divert traffic around the incident. Emergency vehicles must be allowed access to the incident. If using the shoulder as a diversion route for the general traffic would impede the emergency vehicles then another route must be chosen. The available lanes on the freeway should also be used for traffic to travel past the incident if possible.

If the queue length and delay are so severe that traffic is not moving efficiently, then a route off of the freeway should be determined. In the case of I-270, it was decided that MD 355 would be the best alternative route to divert the traffic through the corridor. MD 355 runs parallel to I-270 throughout Montgomery County. MD 355 is located east of I-270.

If the condition of the traffic situation on MD 355 is severe then the HOV lane should be considered. The criteria set in the following section should be used to determine if the HOV lane should be opened to general traffic. Since the HOV lanes on I-270 are concurrent lanes separated from the mainlanes only by a buffer they are very accessible to the general traffic. The HOV lanes are only restricted during peak hours. Therefore, in order to avoid driver confusion it is suggested that if the restrictions are lifted then the HOV lanes should remain open to all traffic the duration of the peak operating period.

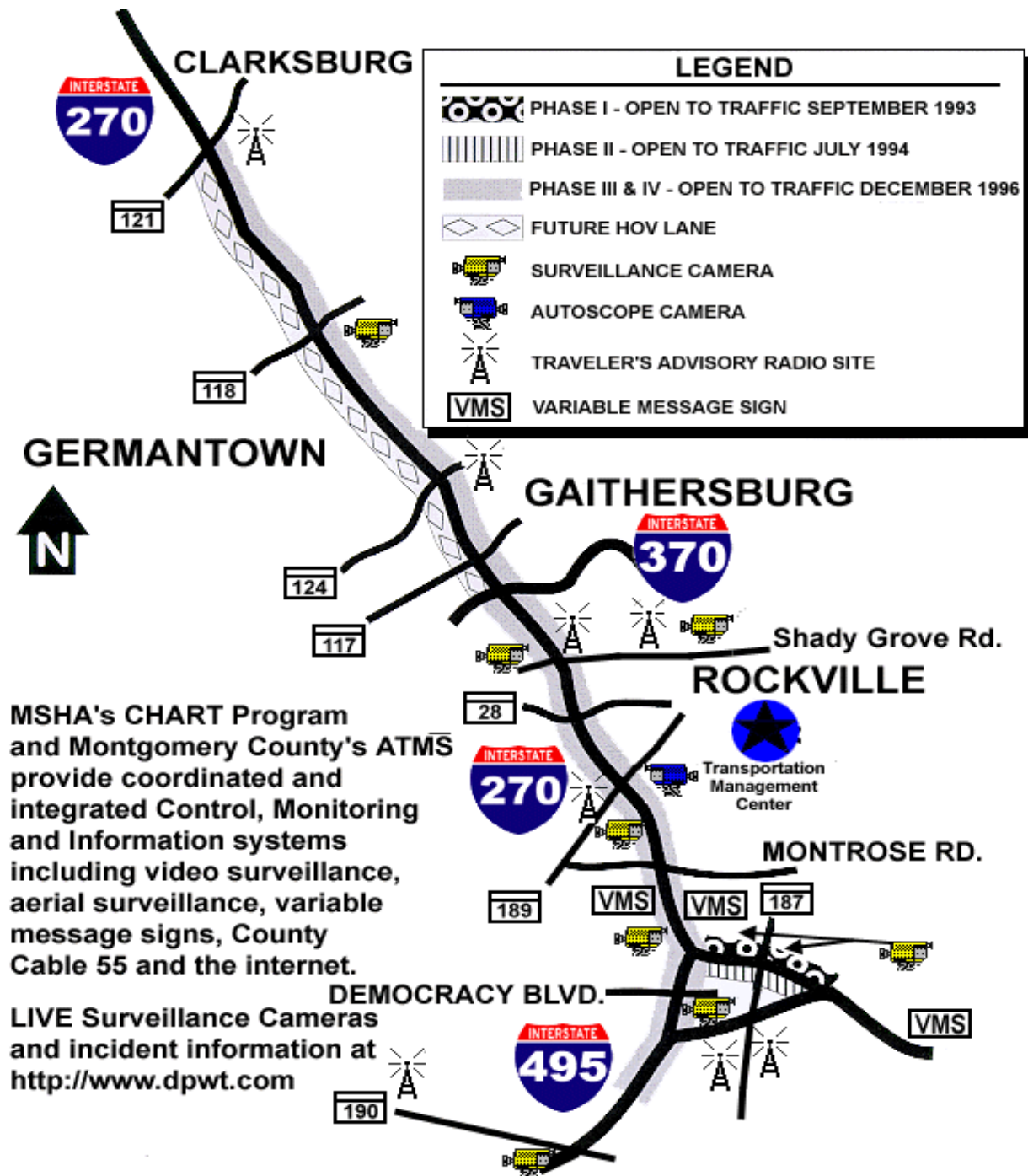


Figure 7. I-270 HOV Lane Sequencing Map (14)

Define Criteria

The criteria used to decide if the HOV lane should be opened needs to be determined. The decision should be made based on the severity of the incident, time of day, impact on mainlane traffic and availability of alternate routes. As stated earlier in the report, the HOV lane should only be used as a last option. It is important to provide reliable travel time savings for the HOV users. Therefore, the incident must be considered a major incident or severe weather condition that has the potential to incur significant delay on the mainlanes. If the capacity is reduced by 50 percent on a freeway for more than an hour with a volume-capacity ratio of 0.7 then the alternative routes must be able to handle 33 percent of the traffic on the freeway in order to maintain the desired volume-capacity ratio of 0.95. If the alternative routes off of the freeway and the remaining mainlanes cannot handle this amount of traffic then the HOV lane should be opened. The availability of the alteranitive routes would be determined by the TMC. These criteria need to be taken into account but the decision is ultimately a judgement call by the response team on the scene and in the traffic management center.

Development of Signing and Other Traffic Devices

Motorists need to be well informed of any traffic situation which might cause them significant delay and informed how to avoid the problem. According to Figure 7, Maryland State Highway Administration has three variable message signs on I-270 located in the vicinity of Rockville. They are located in the following locations:

- Prior to the I-495 Split
- Prior to Exit 4
- South of Middlebrook Road

The messages on the signs need to be carefully worded so that the motorist will receive the proper information in order to avoid any serious delays. The message would need to contain a problem statement, location and an action statement. The following is an example of what should be included on the variable message sign if the HOV lane has been opened to all traffic.

MAJOR ACCIDENT
2 MILES AHEAD
USE HOV LANE

Coordination With the Media

The most successful way to reach the public with traffic information is through the media. The radio and television media are very effective ways to provide information. The incident management team should inform the media to give information on I-270. If the HOV lane is being opened to general traffic then the following information should be provided to the public:

- Level of congestion on the freeway
- Location of the accident
- Suggested alternate routes other than the freeway
- HOV restrictions have been lowered for the duration of the peak period

This information can be broadcast on newscasts, radio stations and on the internet. Traveler's Advisory Radio (TAR) should also be used extensively. I-270 has a network of towers used for sending the signal for the TAR which is shown in Figure 7.

Final Implementation

Once all of the agencies have formed partnerships, diversion routes have been chosen, criteria has been selected, variable message signs are in place and the communication with the media has been established, it is important to test the equipment before the first incident or major weather storm. The signs should be controlled at one central location. The Traffic Management Center (TMC) is located in Rockville as shown in Figure 7. The TMC has the capability to operate traffic devices. The catalog of possible messages to be shown on the variable message signs should be entered into the computer system.

An evaluation of the HOV diversion plan should be constantly performed. The improvement of traffic movement on the mainlanes should be determined by analyzing length of queue and the volume-capacity ratio on the freeway. The cameras and detectors should be used to determine this information. The diversion routes should be evaluated to determine if they were overloaded and if they caused significant delay to motorists and bus riders. Public opinion should also be logged to determine if the public supported the decision to lift the HOV restrictions.

CONCLUSIONS

Providing specific criteria for a response team in order to make a good decision is extremely useful. However, the developed criteria cannot account for every situation and location. Therefore, the decision is heavily based on the good judgement and experience of the response team. One of the information contacts used in this report said that making a decision to open the HOV lane to general traffic during a severe situation “is more of an art than a science” (21). None of the agencies that were interviewed except Virginia even cited specific guidelines that are followed to determine if the HOV lane restrictions should be lifted. However, it is the belief of the author that more specific criteria would benefit the response team because they would have more reliable information upon which to base their decision.

Another problem in opening the HOV lane to general traffic is the political aspect of the subject. Agencies do not want to disrupt the flow of the HOV lanes because of the commitment to travel time savings that has been made to the users. The users expect a specific level of service each day on the HOV lane. However, in order to benefit the total freeway system it is sometimes necessary to open the HOV lane up to all traffic. Obviously, this will limit the effectiveness of the HOV lane. The general traffic would not accept severely congested conditions on the mainlanes due to a severe situation while the HOV lane is moving at free flow speed. Agencies are forced to walk a very fine line in order to please both the HOV users and general traffic, some of whom are against HOV lanes. It is the belief of the author that specific criteria will benefit the HOV diversion process because by following certain guidelines for each decision a level of consistency will be established. It is believed that consistent decision making will ease the tension of the users of the HOV lane and general purpose lanes because they will better understand the reason for opening the HOV lane to general traffic. Therefore, good decisions must be made in the field that are justified by specified criteria.

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APPENDIX

Guideline Questions for Interviews

1. Describe your general operating characteristics, i.e., hours of operation and occupancy requirements.
2. What are the indicators of the traffic situation, i.e., loop detectors, radar, video, regular police patrol?
3. Which agencies are responsible for the incident management and HOV lane operations in your area?
4. Do you allow general traffic to divert to HOV lanes during major incidents and/or severe weather conditions?
5. Do you allow the use of the HOV lane by general traffic for holiday traffic?
6. What criteria are used to determine if the HOV lane should be opened to the general traffic during serious unplanned incidents?

7. Who makes the decision to open the HOV lane?
8. What is the diversion plan that is used to divert general traffic into the HOV lane?
9. What type of technology is used in the diversion plan?
10. What specific information does the driver need in order to successfully divert? How do you communicate with them?
11. What assumptions are made about the motorists?
12. How long is the general traffic allowed to travel on the HOV lane?
13. What is your experience with the success of your diversion strategies? What specific problems have you encountered?
14. Are there performance measures that you use to determine the effectiveness of the plan, i.e., motorist delay, queue length, estimated secondary accidents or estimated flow rate before and during the incident?
15. How many motorists choose to divert? Are they forced to divert?
16. How do the different agencies coordinate in the event of a major incident or severe weather conditions?
17. Is there an operations center where information from the police and/or other highway operating personnel to the other agencies involved is relayed?
18. For 24-hour HOV lanes, when are the general traffic forced back on the HOV lane?



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**APPLICATION OF ITS TECHNOLOGY
TO HURRICANE EVACUATION ROUTES**

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SUMMARY

This study investigated the enhancement of hurricane evacuation procedures through the application of ITS technologies. The objectives inherent to accomplishing this goal include identification of areas with hurricane evacuation practices, assessment of the effectiveness of current practices, identification of problems and voids of current practices, identification of feasible ITS technologies for application, development of hurricane evacuation guidelines, and application of the guidelines to a case study.

The development of a set of hurricane evacuation guidelines included an extensive literature review and numerous interviews. The literature review consisted of an assessment of current evacuation practices, recommended evacuation practices, and available ITS technologies. Current evacuation practices were further assessed in interviews with various state emergency management agencies along the Gulf and Atlantic coasts.

An assessment of current evacuation practices included the following topics: training, evacuation route development, coordination agreements, equipment and personnel resources, deciding when to evacuate, public notification, communications, traffic control devices, traffic management, and agency experience.

Both existing and developing ITS technologies were considered for use during evacuations. While existing technologies may be applied at present, developing technologies may be included in the planning process for the future. ITS technologies of particular concern include geographic information systems, advanced traveler information systems, real-time traffic detection, real-time information displays, in-vehicle traveler information systems, and laptop communication systems.

Based on the literature review and interviews, the author established a general set of hurricane evacuation guidelines pertaining to practices and technologies that have proven to be effective and may also potentially solve some of the problems associated with existing practices. These guidelines encompass the areas of planning and preparation, making the evacuation decision, public notification, traffic management during the evacuation, and preparation for the future. A case study of Galveston, Texas illustrated the application of the evacuation guidelines.

Overall, hurricane evacuation procedures must be continually assessed and updated to reflect changes in the transportation system and to further improve safety and efficiency. The author's guidelines should be applied to specific regions when feasible. Additionally, developing ITS technologies should be incorporated into the planning process to prepare for future implementation.

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INTRODUCTION

Hurricane season lasts from June through November and presents great concern to residents of barrier islands and coastal regions of the United States. Areas along the Gulf and Atlantic Coasts are of particular concern due to frequent and severe hurricanes in past years. Due to the severity of many hurricanes, sizable coastal areas must be evacuated to ensure the safety of residents and visitors alike. Such large-scale evacuations cause extensive traffic problems due to massive numbers of people using the street and highway networks at the same time. Not all transportation systems are equipped to handle such evacuation situations.

Increasing efforts to prepare for and respond to hurricanes have led to the formation of numerous government agencies at all levels to specifically handle emergency situations. These agencies vary in methodology and approach, but all maintain the same common goal: safe and efficient evacuation of people during emergency situations such as hurricanes. Much can be learned from the emergency management systems developed by these agencies with regard to handling evacuation situations. However, more research can help to improve hurricane evacuation procedures.

Problem Statement

Although many government agencies have emergency management systems in place, the question remains: Are they working effectively? Hurricane evacuations still produce heavy congestion and raise safety concerns as motorists try to evacuate. Evacuations must be conducted in a timely manner to ensure evacuees reach a safe destination before the hurricane arrives. Further documentation of transportation operations during hurricane evacuations is needed to assess safety and efficiency issues. In addition, the application of ITS technology may help increase safety and efficiency and decrease the time required for evacuation. Documentation of these issues will provide the basis for a set of hurricane evacuation guidelines.

Research Objectives

The main purpose of this research project is to assess current hurricane evacuation procedures and make suggestions for improvement with the application of ITS technology. The objectives inherent to attaining this goal include to:

- Identify areas with hurricane evacuation procedures;
- Assess the effectiveness of current practices;
- Identify problems and voids of current practices;
- Identify feasible ITS technologies for use in hurricane evacuation procedures;
- Develop hurricane evacuation guidelines using effective existing practices and ITS technologies; and
- Apply these guidelines to an area with hurricane evacuation needs.

Scope

This study is limited to analysis of the evacuation process within a specific region with regard to preparation and the actual evacuation. It does not focus on coordination with destination cities of evacuees and directing traffic to shelter areas, but may touch on these areas as part of preparation. The task of managing traffic returning to the region once the hurricane no longer poses a threat is not examined.

Organization of Report

The literature review for this paper extends through the Background, Evacuation Practices, and ITS Technologies sections. The Background section includes transportation emergencies and the agencies that handle them, as well as a general overview of hurricanes in general. Evacuation procedures utilized by various agencies, as well as practices that have been recommended by experts, are summarized in the

Evacuation Practices Section. The Agency Experience section contains the results of interviews about evacuation practices used by various state emergency management agencies. The ITS Technologies section includes available ITS technologies that could be applied to evacuation procedures. Based on the Evacuation Practices, Agency Experience, and ITS Technologies, the section on Hurricane Evacuation Guidelines outlines recommended practices available for enhancement of current evacuation systems. These guidelines are applied to Galveston in the Case Study: Galveston, Texas section. Finally, Conclusions and Recommendations are set forth in the last section.

BACKGROUND

Most levels of government set up agencies specifically for the management of all transportation emergencies. These agencies include hurricane evacuations in their scope, and hurricanes must be understood in general before one can develop evacuation procedures.

Transportation Emergencies

Transportation emergencies occur when an extraordinary event affects the transportation system and causes congestion, delay, confusion, and/or general disruption of one or more modes of transportation in such a way that the impacts are not part of day-to-day transportation operations (1). Traffic impacts may be severe, of long duration, or require special motorist reactions. Transportation emergencies may result as one of three types of hazards: 1) natural or weather related, 2) technological, and 3) civil/political. Table 1 summarizes the possible hazards in each category (2,3). Some emergencies, such as tornadoes or hazardous materials spills, are reactionary and cannot provoke response until they occur. Other emergencies, such as hurricanes and nuclear/chemical plant disasters, can be planned for proactively.

Table 1. Possible Hazards that Cause Transportation Emergencies (2,3).

Natural	Technological	Civil/Political
Hurricanes Flooding Tornadoes Volcanic Eruptions Wildfires Fog Ice and Snow Storms Earthquakes Asteroid and Comet Impacts	Hazardous Materials Incidents Radiological Incidents Nuclear Power Plant Incidents Chemical Plant Incidents Utility or Telecommunications Failures Computer Viruses	Terrorism Civil Disorder/Riots Weapons of Mass Destruction Bridge or Pavement Failure Major Accidents

The use of forecasting technology allows prediction of hurricane arrivals 24 to 36 hours prior to landfall, which provides key agencies with time to prevent the loss of lives through the implementation of evacuation measures. In this regard, evacuation planning can be conducted far in advance of hurricane season to prepare evacuation plans and procedures for use should the need arise. Advance planning includes identification of hurricane frequency, anticipated hurricane impacts on a region, and mitigation procedures to minimize the impacts and return the environment to a state of normalcy (4).

Agency Involvement

With respect to hurricane evacuations, the federal, state, and local levels conduct transportation planning. Originally, the duties of the Federal Highway Administration included the development of a national emergency highway traffic regulation plan in 1969 (1). In 1979, the Federal Emergency Management Agency was created to assist state and local governments with natural disaster preparedness planning. Their mission is to reduce the loss of lives and property and to use an emergency management program of mitigation, preparedness, response, and recovery to protect the nation's infrastructure (5). In addition, the Office of Emergency Transportation, a branch of the United States Department of Transportation, has responsibility for the emergency preparedness of the transportation system (1). They operate a 24-hour Crisis Management Center which serves as a central location for emergency transportation response (6).

Apart from the federal agencies involved, each state possesses some type of emergency management agency to handle major emergencies. The federal government provided a Guide for Emergency Highway Traffic Regulation in 1985 to provide guidance and encourage each state to develop specific emergency plans for their particular political, geographic, and traffic characteristics (1). Each state emergency management agency serves as the lead agency and works with other supporting state agencies, private organizations, and volunteer organizations. They also encourage each local region to develop emergency plans of their own. When the threat of a hurricane approaches, the local government usually makes the official decision of whether or not evacuation is needed.

Hurricanes

Hurricanes are defined as tropical storms with surface winds that reach a constant speed of 74 miles per hour or more (7). In some parts of the world they are known as typhoons or tropical cyclones. They occur when low pressure disturbances form in the atmosphere between the 5° and 30° latitudes in both the northern and southern hemispheres (8). These storms spiral around a calm center known as the eye of the storm, and effects of a hurricane may extend as far as 400 miles away from the eye of the storm. One hurricane can potentially last for more than two weeks over open water and could run a path across the entire eastern seaboard (9).

Hurricane Effects

As a hurricane approaches land, the combination of low atmospheric pressure and wind draws ocean water inland and causes waves and tides to raise the water level in a phenomenon known as storm surge (8). The storm surge may rise up to 20 feet, range from 50 to 100 miles wide, and last for several hours (7). This causes many fatalities associated with hurricanes and has the potential to devastate coastal communities.

In addition to storm surge, hurricanes may produce additional weather effects. A fully developed hurricane may produce heavy rainfall of approximately six to ten inches as it passes, with a possibility of amounting to as much as 40 inches (8). Excessive rain and flooding of inland streams and rivers may cause landslides (7). Also, hurricanes may spawn tornadoes at landfall because of the existence of ambient conditions for tornado formation (10).

Hurricane Intensity Classification

The Saffir-Simpson Scale classifies hurricane intensity from Category 1 to 5 based on rotational wind speeds and expected damage (11). Most people term Categories 3, 4, and 5 as "major" hurricanes. Table 2 outlines the Saffir-Simpson Scale with regard to maximum wind speed, storm surge, damage, and examples of North American hurricanes (10). Emergency management officials often use the category of a hurricane as a criteria for determining whether or not to issue an evacuation.

Table 2. Saffir-Simpson Hurricane Intensity Scale (10).

Category	Maximum Wind Speed (mph)	Storm Surge (ft)	Damage Level	North American Examples
1	74 - 96	3 - 5	Minimal	Hurricane Joey (1989)
2	97 - 111	6 - 8	Moderate	Hurricane Bob (1991)
3	112 - 131	9 - 12	Extensive	Hurricane Gloria (1985)
4	132 - 155	13 - 18	Extreme	Hurricane Andrew (1992)
5	156+	19+	Catastrophic	Hurricane Camille (1969)

Hurricane Statistics

Each year, approximately ten tropical cyclones develop in the North Atlantic (7). Of these ten cyclones, six are likely to strengthen to hurricane proportion, of which two will probably strike the United States' coast. Approximately two major hurricanes (Category 3, 4, or 5) hit the United States every three years.

Advances in technology and severe weather detection have decreased the number of hurricane fatalities in the United States. In 1900, the Galveston, Texas hurricane took over 6,000 lives (maybe as many as 10,000), which amounts to the most fatalities in United States history for a natural disaster (7, 10). After the first decade of this century, hurricane fatalities dropped off to approximately 1,000 to 2,000 per decade up through the 1960's (12). The 1970's saw about 250 hurricane-related deaths and approximately 100 occurred during the 1980's. Up through 1995, the 1990's have experienced less than 100 deaths. The population at greatest risk during a hurricane, also termed the vulnerable population, includes those who live in areas subject to storm surge and those who reside in manufactured homes (11).

Hurricane Tracking

The National Weather Service is the lead US agency for tracking severe weather (13). Meteorologists have made advances in detecting tropical cyclone formation from distant waters with the help of earth-orbiting and geostationary satellites (8). The National Weather Service issues a hurricane watch when the threat of hurricane conditions in a specific area is 24 to 36 hours away (7). They increase the watch to a hurricane warning when hurricane conditions are expected in less than 24 hours. In a 24-hour forecast, cyclone tracks can be predicted within an error of 10 degrees, which relates to the hurricane striking within 115 miles of its estimated landfall point (8). Once hurricane watches and warnings have been issued for an area, the appropriate officials must decide whether or not a precautionary or mandatory evacuation are in order.

EVACUATION PRACTICES

Current evacuation procedures are assessed to identify good practices, problems, and voids. Additional procedures are identified in the next section on agency experience. Reliable and effective methods are included later in the evacuation guidelines.

Training

Training of personnel and volunteers plays an important part of preparation for hurricane evacuations. Some common forms of training include workshops, short courses, conferences, video training tapes, informal staff meetings, and mock disaster exercises (3). These types of exercises, especially mock disaster exercises, help improve coordination within and among agencies and helps pinpoint strengths and weaknesses in existing evacuation plans (14). Training also promotes safe practices and helps minimize liability (3).

Evacuation Route Development

Evacuation routes must be developed in advance and brought to the public's attention in order for evacuations to run smoothly. Feasible evacuation routes should be selected based on their location, capacity, survivability, ease of restoration, functional service, and strategic characteristics (1). In addition to planning routes, evacuation zones are established to determine the vulnerabilities of the area's storm surge, evacuation routes, and shelter locations (12). The natural, demographic, and political features of an area help determine the shape of the zones and the identification of zones is made readily available to the public. This section includes an analysis of the use of demand, capacity, and human behavior to help determine evacuation routes and clearance time. The methods presented are extremely generalized and only represent one form of modeling. Numerous types of modeling techniques could be applied to hurricane evacuation systems.

Demand

Demand is the number of vehicles, or people, that wish to travel past a point during a specific time period. Demand calculations vary, but the following summarizes a basic process for demand estimation based on demographic (number of residents and tourists in area), vehicle (number of people to evacuate per vehicle), and response factors (15). Response factors can be estimated two ways: 1) everybody will evacuate, or 2) the people most likely to leave (determined by behavioral analysis) will evacuate. The percentage of people likely to evacuate ranges from 30 – 100 percent. Once the demographic, vehicle, and response factors have been determined, the following procedure estimates demand:

- Estimate the population using US Census data;
- Determine current per capita vehicle rates for study area;
- Determine the maximum number of vehicles by multiplying the population by the per capita rate; and
- Reduce the demand by the appropriate response factor (0.30 to 1.00).

Capacity

The *Highway Capacity Manual* defines capacity as “the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions” (16). If capacity exceeds demand, some of the possible roadway capacity is lost over time (15). The roadway section with the least capacity represents the entire evacuation route's capacity. Generalized capacity values may be developed for various facility types by applying ambient condition and poor roadway condition adjustment factors to ideal capacity values as set forth in the *Highway Capacity Manual* (15, 16).

Clearance Time

Clearance time represents the total time elapsed from an evacuation issuance until all vehicles have cleared the roads in an evacuation area (11). The actual clearance point varies among agencies. Calculation of clearance time depends highly on human behavior, demand, capacity, time of day, and hurricane category. A behavioral-based simulation model includes three components of clearance time: 1) initial warning time, 2) individuals' preparation time, and 3) network clearance time (17). The initial warning time varies for each

individual as they decide whether or not to evacuate and as they search for confirmation of the evacuation recommendation. Once an individual decides to evacuate, preparation time is needed to secure homes and property, contact family and friends, pack a few belongings, and other such matters. Network clearance time can be estimated by the demand (total number of vehicles) divided by the generalized capacity for each link of evacuation routes. The overall clearance time helps determine how far in advance to issue an evacuation.

Coordination Agreements

A single agency cannot handle a major emergency alone. Cooperation and teamwork is needed from all affected agencies (14). Agreements among agencies can be either informal or formal. Important items for consideration prior to an emergency that should be part of an agreement include (1):

- Chain of command within an agency and among agencies;
- Address and phone list of key personnel in each agency;
- Agency lists of available manpower and equipment capabilities;
- Method and sequence of alerting each agency of an emergency; and
- Mutual-aid agreements.

Equipment and Personnel Resource Assessment

During an emergency such as a hurricane evacuation, responses to the situation must be made quickly. Precious time can be saved if each agency involved draws up equipment and personnel lists during their preparation efforts (1). This also helps the response efforts run more efficiently.

Equipment Resources

The Guide for Emergency Highway Transportation Regulation suggests the development of a jurisdictional map and a listing of storage locations, including the materials and equipment stored at each facility (1). Developing equipment resource lists should be an easy task because many agencies keep track of their equipment and supplies as a part of their normal daily activities (14). In addition, officials involved in Hurricane Hugo in 1989 suggest real-time assessment of resources throughout the emergency (1). Computer technology also aids resource management, but hard copies of the equipment lists should be kept on hand in case of electrical power loss or computer networking failure.

Personnel Resources

Personnel management is also essential for the smooth flow of evacuation operations. Agency actions to manage personnel during an emergency include (3):

- Providing duplicity in key positions;
- Establishing relief schedules to rotate personnel and allow sleep during emergencies lasting longer than 24 hours; and
- Establishing mechanisms to allow personnel to communicate with their families.

Deciding When to Evacuate

Deciding whether or not to evacuate a region is a tough decision, usually made on the local level. If an evacuation is ordered too early and the hurricane makes landfall outside of the error range, the public is less likely to respond next time. Several agencies and tools help those in charge with their ultimate decision.

National Weather Service

The National Weather Service (NWS) is the only official United States agency to issue warnings during life-threatening weather situations (13). The NWS stores data in a national database available to government agencies, the private sector, the public, and the global community. Their web site also provides an interactive weather information network, which provides real-time information, forecasts, watches, and warnings for all regions of the United States.

NOAA Weather Radio

National Oceanic and Atmospheric Administration (NOAA) Weather Radio is a nationwide network of radio stations that broadcasts National Weather Service forecasts, watches, warnings, and hazard information 24 hours a day as a public service (18). NOAA Weather Radios are equipped with an alarm that sounds when life-threatening situations arise. Other features such as strobe lights, pagers, bed-shakers, personal computers, and text printers are available for the hearing- and visually-impaired. A new digital technology called Specific Area Message Encoding (SAME) allows broadcasts to be targeted to specific areas, such as a county or region. The SAME technology also allows listeners to pre-select the National Weather Service alerts they want to receive based on their county. To receive NOAA Weather Radio, special receivers must be purchased ranging in price from about 25 to 100 dollars. Public safety experts would like to one day see NOAA Weather Radio receivers as standard equipment in every home. Several areas have received funding and implemented programs to install NOAA Weather Radio in public facilities.

Emergency Alert System

The Emergency Alert System (EAS) is a tool that allows the President and others to warn the public about emergency situations (19). The EAS interrupts regular television and radio programming to provide emergency guidance to specific viewing and listening areas. The EAS is implemented by the Federal Communications Commission in conjunction with the National Weather Service and Federal Emergency Management Agency. Currently, the EAS reaches most citizens. The digital system used by the EAS allows signals to travel over non-broadcast frequencies and telephone lines. For a small fee, new specially equipped consumer products, such as cellular phones, pagers, and other devices, can receive EAS messages.

Emergency Managers Weather Information Network

The Emergency Managers Weather Information Network (EMWIN) provides a service that allows users to obtain almost real-time information, such as weather forecasts, warnings, and other information, from the National Weather Service (20). The use of EMWIN is primarily intended for use by emergency managers and public safety officials. EMWIN can be obtained by direct satellite broadcast and repeat radio broadcast, both of which require the purchase of special hardware. For those who do not wish to purchase the hardware, several methods exist for obtaining EMWIN feed directly over the internet.

HURREVAC

HURREVAC (HURRICane EVACuation program) is an US government computer program that is restricted to use by official government emergency managers (21). The program tracks hurricanes and helps users reach evacuation decisions for their communities. In 1989, government officials in Georgia, North Carolina, and South Carolina successfully used HURREVAC to help them decide upon an evacuation order for Hurricane Hugo (1). HURREVAC is only one of many software tools available.

SLOSH

The National Weather Service developed the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model to calculate potential storm surge heights produced by hurricanes (11). In selected Gulf and Atlantic basins, the SLOSH model provides real-time surge forecasts for approaching hurricanes. In addition to surge height calculation, the SLOSH model can simulate storm surge routing into sounds, bays, estuaries, and coastal river basins. In addition to the use of HURREVAC in 1989, Georgia, North Carolina, and South Carolina government officials also successfully used the SLOSH model to aid them in their Hurricane Hugo evacuation decision (1).

The Public

Positive public response to evacuation warnings is essential for the successful, safe, and efficient evacuation of an area. Prior to hurricane season, public awareness campaigns remind the public to prepare for hurricanes. As a hurricane approaches, the appropriate notification procedures and messages must be used to convince the public that evacuation is in their best interest.

Public Awareness Campaigns

Several effective methods to promote public awareness include: (3)

- Educational campaigns;
- Public service announcements;
- Brochures illustrating designated evacuation routes; and
- Contact information during emergencies (i.e., internet, phone number).

Public Notification of Evacuation

Apart from hurricane warnings provided by the Emergency Alert System, the public needs supplemental notification concerning what actions should be taken. Behavioral analysis indicates most people respond to an evacuation directive with denial or the need for confirmation (22). To promote evacuation, the public must be convinced they are in danger. The display of past hurricane destruction on television just prior to making an evacuation notice has been effective (23).

An important aspect of public notification is timely and consistent information. For this reason, a public information coordinator should be assigned to disseminate transportation information directly to the media and public (14). Key personnel involved in the evacuation should direct all questions and comments to the public information coordinator to reduce the potential for the distribution of inaccurate or conflicting information. The public information coordinator should also maintain close ties with the media.

Communications

Communications abilities, both within and among agencies, is of critical importance during an evacuation. Within many transportation agencies, good communication systems already exist and can be used during an emergency. However, systems are needed to communicate among agencies because the telephone system is often inoperable during large-scale emergencies. The telephone system may be down due to electrical outages, damage, or an overwhelming number of calls (24). The Federal Communications Commission has recognized the Public Information Emergency System (PIES) as an exemplary radio communications network that should be modeled by other areas (1). PIES is currently in use in the Houston/Galveston area of Texas and utilizes a special radio frequency that links Emergency Operations Centers in the area with one another and with media outlets. The use of Amateur Radio Emergency Service (ARES) and Radio Amateur Civil

Emergency Services (RACES) have proven useful in past emergencies (14). Both organizations provide volunteer radio communication services to all levels of government and non-profit organizations.

In the event of a breakdown in the main communication system, back-up communication systems should be available (25). This is necessary in case the regular communication system loses power or problems arise. In addition, back-up communication systems can supplement the regular communication system by allowing more communication than normally possible.

Transportation System Assessment

The most fundamental preparation measure a transportation agency can take is to assess the existing transportation system and analyze its ability to function during a large-scale hurricane evacuation (14). At a minimum, the assessment should include:

- Traffic operations analysis of critical signalized and unsignalized intersections;
- Capacity analysis of key evacuation routes;
- Identification of “sensitive” locations within the system (i.e., schools, hospitals, etc.); and
- Assessment of manpower and traffic control device needs for real-time traffic management if needed.

Assessment of the transportation system should be a continuous process to accommodate changes in the system. Temporary conditions, such as construction or malfunctioning traffic control devices, should also be kept up-to-date and included in the assessment (3).

Traffic Control Devices

Traffic control devices provide direction during an evacuation. The public recognizes commonly used devices and follows them well.

Channelizing Devices

Channelizing devices such as cones, tubes, barrels, and barricades are useful traffic control devices during hurricane evacuations. Some of their potential uses include: (1)

- Roadway or ramp closure;
- Splitting a ramp into two narrow lanes to increase capacity; and
- Supplementation of law enforcement directives.

All channelizing devices should be adequately weighted down because of potential weather hazards (26).

Static Signs

The main static sign used for hurricane evacuations is the evacuation route marker, which is included in the *Manual on Uniform Traffic Control Devices* (MUTCD) (27). The circular sign measures 18 inches in diameter and reads “EVACUATION ROUTE” in white legend on a blue background. The legend also includes a white reflectorized arrow, which varies in direction. The MUTCD suggests the placement of evacuation route markers 150 to 300 feet in advance of and at any turn in an approved evacuation route and as straight-ahead confirmation where needed. A public awareness campaign should include the meaning and existence of the evacuation routes and markers to prevent confusion (3).

Stop signs, detour signs, arrow signs, and road closed signs may also be erected (24). These signs can be mounted on barricades as typically required or simply mounted on or leaned against anything, such as an agency vehicle. Sometimes stop signs successfully replace a signal when power has been lost (1).

Traffic Management

Many traffic management options exist to help expedite the evacuation process. Negative impacts must also be taken into account when considering many of the following procedures.

Emergency Operations Center

Emergency Operations Centers (EOC's) are commonly used to control all emergency activities (i.e., traffic control, resident evacuation, restriction of access to the emergency area, etc.) in a coordinated manner (1). EOC's exist at the federal, state, and local level. The local emergency management coordinator or law enforcement commander typically controls a regional EOC and representatives from other support agencies often report to the EOC.

Law Enforcement

Law enforcement officers play a critical role in hurricane evacuations, especially with respect to traffic management. Often, active traffic control is needed to aid the flow of traffic at critical intersections or to take care of traffic accidents.

Signal Issues

Increasing green time and/or the progression band for a given direction has proven to be an effective method for increasing flow on signalized roadways (3, 25). This method should be applied to the direction of the traffic heading out of the evacuation zone in such a manner to ensure the cross-streets are not too heavily penalized.. This is a practical technique for agencies with computerized control systems with the capability to change timing plans from a central location.

Agencies may consider the temporary removal of signal heads before a hurricane arrives along with placement of law enforcement officers at intersections to direct traffic (3). This preventative measure can prevent signal head destruction during a hurricane and allows an agency to quickly replace the signal heads after the hurricane to reestablish control of the intersection as evacuees begin returning. During Hurricane Hugo in 1989, approximately 275 signal heads were completely ripped off spanwire and destroyed and about 500 signal heads were damaged to some extent in South Carolina (26).

Reversible Flow

The conversion of roadways to reversible, or one-way, flow has been considered by several agencies and mostly negative feedback resulted. The negative aspects of reversible flow include: (3, 14, 25)

- Violation of driver expectancy;
- Safety issues;
- Extensive manpower for implementation;
- Problems in converting the roadway back to two-way flow without creating bottlenecks; and
- Dangerous geometric implications (i.e., adverse superelevation, limited sight distance, etc.).

Some agencies feel reversible flow may have some benefits for certain situations, particularly for short sections of roadway (3, 25). This might also be effective when evacuation needs to occur in a shorter time frame than possible. For this technique to work, a special lane would have to be set aside to allow emergency vehicles to travel in the opposite direction if needed.

High Occupancy Vehicle Lane Usage

During an evacuation, officials may opt to allow high occupancy vehicle (HOV) lanes to be opened to all traffic regardless of occupancy restrictions (3, 25). Several issues need to be examined when considering this option. Bottlenecks may form at the terminus of the HOV lane, which may reduce capacity and offset any potential benefits. Confusion may result because not all motorists may be familiar with HOV facilities. Public awareness prior to evacuation is needed to ease confusion. Furthermore, dropping occupancy limitations sets precedents for similar actions in the future and this may not be desired.

An alternative to lifting occupancy requirements on HOV lanes would be to encourage normal HOV lane usage during evacuations. This might encourage people to travel in groups. Furthermore, “evacuation buses” could be provided to get people to leave their personal vehicles behind, which reduces capacity. The ability of such buses to use the HOV lanes to bypass evacuation congestion might provide strong incentives for their usage.

Shoulders as Temporary Travel Lanes

Some agencies have suggested the use of shoulders as temporary travel lanes during hurricane evacuations (3). This would only prove effective if downstream bottlenecks can be avoided. Also, shoulders on both sides of the roadway would be necessary so the outer shoulder could be utilized by emergency vehicles and disabled vehicles. Measures should be taken to ease motorist confusion because driving on the shoulder violates driver expectancies. This could be achieved through the use of temporary signing and law enforcement personnel on site to direct traffic to the shoulder.

Suspension of Tolls

Some agencies have suspended toll collection during past emergencies to increase capacity and reduce bottlenecks created by the toll collection process (3, 25). Ideal situations for using this policy include:

- When the evacuation of an area needs to take place in a shorter time frame than possible; and
- No suitable alternative evacuation routes exist and citizens would be forced to pay tolls.

To invoke this practice, cooperation agreements must be established between public agencies and the toll authority prior to implementation. Motorists would need to be notified through the use of special signing, real-time information displays, or public service announcements. Any types of special vehicle restrictions (i.e., trailers and wide loads) would need to be clearly disseminated. A negative effect of toll suspension is that it sets precedents for future actions.

Tow Truck Usage

Minor vehicular incidents, such as stalled vehicles or fender-benders, may create problems on major evacuation routes, especially if they occur at bottleneck locations (3, 25). During an evacuation, tow trucks could be stationed at bottleneck locations to help detect and clear incidents in order to maintain a roadway’s capacity. Suspension of normal tow truck rotations and special arrangements and location assignments would need to be established. The well-being of the tow truck operators also needs to be considered. In addition, the use of tow trucks along evacuation routes is costly because it may be necessary to pay for the time they provide services on the roadway.

On-Street Parking Restrictions

The restriction of on-street parking along an arterial on an evacuation route could provide an additional travel lane (3, 25). This would only be useful if the increased capacity could be maintained downstream at the end of the route. Also, cars already parked along the street would have to be moved somehow, either by notifying

vehicle owners or using tow trucks. The use of tow trucks could lead to liability and cost issues. In addition, a strong public awareness campaign prior to hurricane season should inform the public of the restrictions.

Minimization of Left-Turning Movements

The restriction of left-turning movements at critical intersections along evacuation routes has the benefits of increasing green time for through movements at signals and reducing blockages in through lanes when left-turn bays are not provided (3, 25). Evacuation routes can also be assigned to minimize left-turn conflicts. This has proven effective in Duval County, Florida, where coastal evacuation zones are set up to feed motorists to the nearest major east-west arterial south of the zone so that right turns are the predominant movement to access evacuation routes (26). Public awareness, special signs, or law enforcement direction of traffic would be needed to uphold this practice.

Vehicle Restrictions

Consideration should be given to the restriction of the movement of some vehicles such as oversize cargoes and mobile homes. Oversize and overweight cargoes can decrease the capacity and safety along evacuation routes (1). In the Florida Keys, the movement of mobile homes is restricted after a hurricane warning is issued because just one disabled mobile home could block the only escape route (26). Mobile homes may also have a tendency to blow over when hurricane strength winds approach.

AGENCY EXPERIENCE

Emergency management and transportation agencies were contacted for interviews in order to learn what practices are used in each state and to assess their effectiveness. State agencies in states along the Gulf Coast and most of the Atlantic Coast were targeted due to their high hurricane frequency. Of ten agencies contacted, seven responded for interviews. Table 3 contains a list of the people interviewed and Appendix A lists sample interview questions asked of each agency. This section summarizes the information collected from interviews and other literature sources.

Table 3. Interview Contacts.

Agency	Contact	Position
Florida Department of Transportation	Jack Brown	State Traffic Operations Engineer
Georgia Emergency Management Agency	Chuck Gregg	Regional Planner and Hurricane Specialist
Gulf Regional Planning Commission	Ken Holland	GIS Specialist
Maryland Emergency Management Agency	Carol Thiel	Hurricane Planner
Mississippi Emergency Management Agency	Leon Schaifer	Deputy Director
	Andy Crawford	Hurricane Program Manager
North Carolina Emergency Management	Tom Hegele	Chief
South Carolina Emergency Preparedness Division	Charmel Mendez	Hurricane Program Manager
Governor's Division of Emergency Management (Texas)	Mike Peacock	Hurricane Planner

Common State Practices

Common practices are used by many of the state agencies surveyed. All seven of the agencies work closely with other transportation-related state agencies such as the Department of Transportation, Department of Public Safety, local emergency management agencies, and state, county, and local law enforcement. They all use the NOAA Weather Radio and the Emergency Alert System to obtain some of their hurricane information. All of them also conduct training programs that range from workshops to table-top and mock exercises. Most of the agencies educate the public about hurricanes through campaigns and Hurricane Awareness Week. The news media (i.e., television, radio, and newspaper) is mainly used to notify the public of hurricane evacuations in the form of press conferences, public service announcements, and statements from state and local officials. Under extreme circumstances, law enforcement personnel drive through key residential and tourist areas with public announcement systems and sirens. Table 4 includes a summary of many of the common traffic control and management practices.

Table 4. Common State Evacuation Practices.

Evacuation Practices	Florida	Georgia	Maryland	Mississippi	North Carolina	South Carolina	Texas
Evacuation Route Markers	✓	✓	✓	✓	✓	✓	✓
Static Evacuation Signs	✓			✓	✓	✓	
Changeable Message Signs	✓	✓	✓	✓	✓		✓
Closed Circuit Television Cameras	✓ ¹						✓ ¹
Lane Control Signals	✓ ¹						✓ ¹
Reversible Flow ²		✓ ³	✓		✓		
Highway Advisory Radio	✓	✓	✓	✓	✓		✓

¹ Only used if part of an existing regional system.

² Mostly used on short sections of roadway, bridges, and roadways to barrier islands.

³ Contingency plan for extreme cases that has yet to be used.

Florida

The Florida Division of Emergency Management (FDEM) controls emergency management in the state of Florida. Evacuation clearance times range from 3.5 to 51 hours depending on the location and the severity of the approaching storm. Decisions to evacuate are made with the help of the Emergency Managers Emergency Information Network (EMWIN) and Florida’s own Florida Warning and Information Network (FWIN). Some areas provide a local 1-800 number to provide the public with information.

The FDEM developed an Emergency Satellite Communications (ESATCOM) system for state-wide communications among the State Warning Point (the state emergency communications center), federal and local government agencies, and other entities (11). The system does not rely on commercial electrical power or overhead terrestrial lines and provides high-speed data transmissions of facsimile, video, and voice.

Traffic control procedures vary throughout the state because of Florida's extensive coastline. Static flip-down signs are used throughout the state to provide information. For instance, a "Wear Seat Belt" sign might flip down to reveal a sign with shelter information. Changeable message signs are utilized when they are already in place in the existing transportation system and are sometimes temporarily moved from construction sites to hurricane evacuation routes. Traffic counters are used on interstates to provide the state Emergency Operations Center with real-time traffic flow data.

Georgia

In Georgia, the lead agency for emergency management is the Georgia Emergency Management Agency (GEMA) (28). Recent hurricane evacuations include Hurricane Hugo (1989), Hurricane Bertha (1996), and Hurricane Fran (1996). Evacuation clearance times range from 9 to 28 hours depending on the size of the county. The evacuations in 1996 were voluntary and only five to ten percent of the affected areas evacuated.

Teleconferences are used to communicate among the agencies involved in the evacuation process. Communication is also made with visitor centers along the major evacuation routes so that motorists stopping at the visitor centers can receive information.

Along major evacuation routes, temporary and manual counters are used to estimate traffic volumes. A contingency plan exists for one-way operations along a segment of IH-16 as a means of last resort. This has never been implemented due to logistics and the number of personnel needed for safe operation.

GEMA recently developed a new emergency management plan that focuses on phased evacuations. Under this plan, evacuations would be ordered in succession of four phases: 1) voluntary evacuation of barrier islands and storm surge zones, 2) mandatory evacuation of barrier islands and storm surge zones, 3) voluntary evacuation of coastal regions, and 4) mandatory evacuation of coastal regions. These phases will be implemented as needed.

Maryland

The Maryland Emergency Management Agency (MEMA), a division of the Maryland Military Department, coordinates emergency management in Maryland (29). During the past two decades, evacuations have only been ordered for Hurricane Gloria (1985) and Hurricane Emily (1993). These evacuations have been voluntary because the state of Maryland does not mandate evacuations.

Evacuation of barrier islands, such as Ocean City, involves conversion of major freeways to one-way operations (30). This is accomplished using changeable message signs and arrow boards along the routes to direct motorists. Shoulders are kept open for disabled vehicles and emergency services vehicles. State Police and barricades and/or barrels are placed at all closed ramps to maintain one-way flow in the appropriate direction. A telecommunications network has been set up between the state Emergency Operations Center and local governments, the federal government, weather services, and other facilities (29). These methods have proven to be effective and reliable. A new evacuation plan includes phased evacuations similar to the methods mentioned by Georgia.

Currently, the DelMarVa Emergency Task Force is constructing a regional evacuation plan for the eastern shores of Delaware, Maryland, and Virginia. This alliance aims to eliminate communication problems across jurisdictional boundaries. A similar regional plan is being developed for several Maryland counties along the western shore of the Chesapeake Bay.

Mississippi

The Mississippi Emergency Management Agency (MEMA) is the lead agency for emergency management in the state of Mississippi (31). Other than several precautionary evacuations issued during the 1990's, only

two other hurricanes have warranted full-scale evacuation in the past two decades: Hurricane Elena (1985) and Hurricane Georges (1998). Evacuation clearance times range from 12 to 24 hours depending on the location and the time of day the evacuation is issued.

Evacuation routes are developed with the aid of Geographic Information Systems (GIS). These routes are developed for each evacuation zone and are based on a factored version of the 1990 Census of Population. Brochures containing evacuation maps are distributed in tourist locations such as hotels and casinos along the coast because tourists and out-of-town visitors are often unfamiliar with the area and do not fully realize the implications of an impending hurricane. The casinos in Mississippi are very cooperative and often help provide funding for the distribution of brochures.

Large static evacuation signs are used to provide information regarding radio station frequencies, shelters, and other general information. Currently, the Mississippi Department of Transportation is in the process of installing traveler information kiosks at 12 rest areas to alert motorists of construction zones and emergency information such as hurricane evacuation routes (32). These kiosks will be free of charge and have been recognized by the Federal Highway Administration as a good practice. Video conference calls are also conducted twice daily between MEMA and the regional Federal Emergency Management Agency, neighboring states and regions, and the National Hurricane Center as a hurricane approaches.

North Carolina

North Carolina Emergency Management (NCEM) is a division of the North Carolina Department of Crime Control and Public Safety (33). Typically North Carolina experiences at least one hurricane or nor'easter per year, but in the last two decades has only evacuated for Hurricane Bob (1991), Hurricane Emily (1993), Hurricane Bertha (1996), Hurricane Fran (1996), and Hurricane Bonnie (1998). Evacuation clearance times for the barrier islands range from 8 to 30 hours, depending on the island.

Bridges and parts of some roadways that connect barrier islands to the mainland are converted to one-way operations and many law enforcement officers are used in this process. Eventually some bridges are closed completely prior to hurricane landfall.

South Carolina

In South Carolina, the state Military Department houses the South Carolina Emergency Preparedness Division (SCEPD) to handle the state's emergency management needs (2). In past years, part or all of the South Carolina coast was evacuated for Hurricane Hugo (1989), Hurricane Bertha (1996), Hurricane Fran (1996), and Hurricane Bonnie (1998). Evacuation clearance times range from 12 to 30 hours depending on the location, month, and tourist activity.

Static signs are used to direct motorists into the appropriate lanes for evacuation routes. The South Carolina Department of Transportation uses counters on the evacuation routes to monitor traffic flow. If the volumes do not indicate that most people have evacuated, more focus is shifted to notifying the public.

Texas

In Texas, the Governor's Division of Emergency Management (DEM) is a part of the Texas Department of Public Safety (9). Hurricane evacuations are not mandatory in Texas, but are strongly encouraged when public safety is at risk. The last hurricane evacuation was recommended in 1992 for Hurricane Andrew. Evacuation clearance times range from two hours for a Category 1 hurricane to 30 hours for a Category 5 hurricane. Clearance times are highly dependent on the coastal area, transportation network of that area, and the category of the hurricane.

Major cities along evacuation routes, such as Houston and San Antonio, use lane control signals and closed circuit television cameras already in place to monitor traffic flow. Conversion of Interstate Highway 37 to reversible flow coming out of Corpus Christi has been planned, but has yet to be implemented.

Problems Identified by State Agencies

All of the agency personnel interviewed addressed various problems associated with hurricane evacuations. The main problem cited by most agencies is convincing the public that it is in their best interest to evacuate. Most people want confirmation of an evacuation order, whether it is mandatory or precautionary. The public is also confused by conflicting information, such as media reports that do not reflect evacuation orders, but instead show clear and sunny conditions along the coast.

Other problems identified deal with communications, special needs, vehicles, accidents, and construction. Many agencies indicated that although communication systems within each agency work well, improvements can still be made to communication systems among agencies. Also, more communication is needed among the personnel of all the participating agencies during evacuations. Special needs citizens (i.e., elderly and handicapped) are not always taken care of during evacuations. Many families evacuate in all of the vehicles they own and try to take part of their property using trailers. Accidents are difficult to take care of during an evacuation because law enforcement personnel are tied up and tow trucks do not operate as they usually do. Lastly, construction work often occurs heavily in the summer months, which provides the potential to slow down traffic along major evacuation routes during hurricane season.

Suggested Solutions

In addition to identifying evacuation problems, the interviews also revealed feasible solutions and other suggestions. Increased public education through various media might help convince people to evacuate. This should include pre-planning suggestions so that the public is not taken by surprise when evacuations are issued. Restrictions on boats and trailers would help increase the capacity on roadways. More evacuation information on static and changeable message signs would help keep the public informed and ease traffic flow. Throughout an evacuation procedure, information could be tracked using emergency management software for later analysis and to share with other emergency management agencies. This would help agencies learn from past experiences and to better prepare for future evacuations.

ITS TECHNOLOGIES

According to the *Highway Capacity Manual*, Intelligent Transportation Systems (ITS) are “considered to include any technology that allows real-time information to be gathered and used by drivers and traffic control system operators to provide better vehicle navigation, roadway system control, or both” (16). Although some of the ITS technologies presented in this section will not be available for several years, others can currently be applied to hurricane evacuations.

Geographic Information Systems

A Geographic Information System (GIS) “is a specialized information management system that can collect, store, retrieve, analyze, and visualize geographic data within a spatial environment” (34). GIS software contains a database and usually contains tools for database management, graphic processing, and spatial analysis. GIS can allow emergency managers quick access to critical information pertaining to a particular location (35). It can also be used to help manage the evacuation process.

Recently, researchers developed a flexible evacuation management system that ties together GIS software and a database management system (DBMS) that integrates dynamic behavioral patterns, the transportation network, and regional land-use information (34). DBMS computer applications help store, retrieve, and

analyze data. Together, DBMS sets up the data management environment, and GIS provides spatial analysis and graphic processing.

Based on local characteristics, such an evacuation management system could be applied to a region based on the time of day an evacuation is issued so that appropriate traffic control measures can be made to reflect the location of the evacuating public.

Advanced Traveler Information Systems

Advanced Traveler Information Systems (ATIS) provide motorists with information prior to a trip. Such a system could be applied to hurricane evacuations in the form of an automated public information system, the world wide web, or multi media kiosks to provide the general public with general and real-time information.

Automated Public Information System

An automated public information system can be very useful in relaying a consistent and trusted message to the public. A good example of an automated public information system exists in the Dallas district of the Texas Department of Transportation (3). They have implemented a voice-mail telephone system with the capability of handling numerous calls simultaneously that has proven to be effective. Information on such a system must be as complete and up-to-date as possible because the system does not allow callers to ask questions.

World Wide Web

The Florida Division of Emergency Management's (FDEM) website provides an excellent example of ATIS already at work. The FDEM web site contains numerous links to hurricane, weather, and disaster agency sites and contains an entire hurricane section (11). On a general information level, the site contains the Regional Evacuation Procedure, hurricane arrival time calculations, evacuation decision-making criteria, preparedness information (i.e., checklist, supply kit, home protection, etc.), and statewide evacuation routes. Real-time information is also provided in the form of current weather and updates about tropical storm threats. Additional real-time information could also be provided in the form of real-time traffic data and travel time information as posted by Houston TranStar (36).

Traveler Information Kiosks

Multimedia kiosks provide travelers with an interactive medium to provide them with information prior to or during a trip (37). Kiosks have the capability to display information in various formats including text, graphics, images, and live video. Public places such as car rental agencies and highway rest areas provide ideal locations for hurricane evacuees to obtain information on hurricane updates, evacuation routes, shelter areas, and construction zones.

Real-Time Traffic Detection

Numerous methods are available for the detection of traffic. Many of these methods include inductance loop, radar, infrared, microwave, audio, and video detection (38). Accuracy and reliability varies for each detection method. Inductive loop detectors are most commonly used by transportation agencies, but two major drawbacks exist in their use during hurricane evacuations (39). One drawback is that a loops sometimes resets itself when a vehicle is stopped over the loop for an extended time period. This is likely to happen during an evacuation. The other drawback is that emergency management officials cannot "see" the roadway conditions with the use of inductive loops. For this reason, some agencies use closed circuit television cameras.

Closed Circuit Television Cameras

Placement of closed circuit television (CCTV) cameras along critical roadways provides real-time video footage of traffic. This allows for fast detection of incidents and congestion. During an evacuation, such real-time visuals could be crucial and possibly life-saving, while also helping to reduce evacuation clearance times (39). Used with real-time information displays and in-vehicle information systems, information from CCTV could be used to re-route traffic around troubled sections of roadway.

Real-Time Information Displays

Real-time information displays convey useful information when motorists need to be kept up-to-date on the hurricane evacuation. This can be achieved by displaying information on changeable message signs and by directing traffic with lane control signals.

Changeable Message Signs

Changeable message signs (also called dynamic or variable message signs by some agencies) are the main traffic control device used for displaying real-time information. For instance, information concerning routes, shelters, upcoming detours, and radio frequencies can be displayed. Messages displayed on changeable message signs should be comprehensible to motorists and supply timely and useful information (25).

Lane Control Signals

Lane control signals display “X”s and arrows over individual travel lanes or alongside the roadway to show whether a lane is open or closed (38). Green arrows, yellow “X”s (or diagonal arrows), and red “X”s indicate if a lane is open, about to close, or closed, respectively. These signals provide motorists with advance warning of lane closures due to incidents and construction, which in effect increases traffic flow during evacuations.

In-Vehicle Traveler Information Systems

In-Vehicle Traveler Information Systems allow motorists to obtain general and real-time information during a trip. With regard to hurricane evacuations, critical information pertaining to weather, evacuation orders, and evacuation routes may be relayed to the motorist. Highway advisory radio is already in use and new developments are being made with automatic vehicle identification and in-vehicle computer systems.

Highway Advisory Radio

Highway Advisory Radio (HAR), a portable, low-power system, broadcasts area-specific traffic information over an AM radio band (38). In the past, HAR has proven to be an effective means of disseminating information on subjects such as incidents, construction, and airport parking. This can also be applied to hurricane evacuations. Often, static signs, portable signs, and changeable message signs display the radio frequency for motorists to use.

Automatic Vehicle Identification

Automatic Vehicle Identification (AVI) technology is advancing with regard to in-vehicle traveler information (36). Developments are currently being made in the area of two-way communication between the roadside and AVI equipment in a vehicle. Ways are currently being explored to broadcast information to vehicles with AVI equipment using commercial radio or highway advisory radio. This type of information would be similar to the information broadcast on changeable message signs and would be disseminated on a location-specific basis. This too, however, has not fully been developed yet. Once completed, real-time weather and traffic information pertaining to hurricane evacuations could be transmitted to motorists with

AVI tags when they pass through specific areas. Agencies are currently trying to get AVI tags placed in more vehicles.

In-Vehicle Computer Systems

In-vehicle computer-based applications should increase dramatically over the next five to ten years with respect to number and variety (40). Preliminary models have been utilized by various automobile manufacturers and rental agencies, but have yet to be perfected and completely implemented by the private sector. On a simplistic level, route guidance systems are intended to provide drivers with basic instructions on how to best reach their destinations (41). On a larger scale, the goal is to provide in-vehicle systems that provide Driver Assistance (DA) systems and Mobile Services and Information (MSI) systems. DA systems include such features as adaptive cruise control, and obstacle warning systems. MSI systems include features such as navigation, roadside assistance, electronic fee payment, real-time traffic information, weather reports, driver-specific comfort and convenience adjustments, and office-in-the-car services. The MSI system could feasibly be extended to provide evacuation routes and real-time weather and traffic updates during a hurricane evacuation.

Although companies are beginning to market in-vehicle computing systems, much work still lies ahead. The DA and MSI systems must be incorporated somehow, standard guidelines must be established, and systems must be designed for compatibility with human information processing capabilities. In addition, a reliable wireless technology has yet to be developed to support the delivery of real-time information. Wireless communication technologies are currently being experimented with. Until these obstacles and others are overcome, route guidance systems will not be applicable to hurricane evacuations. Once it is possible, it could prove very useful in the dissemination of real-time evacuation information.

Laptop Communications System

Recently, the US Department of Justice's National Institute for Justice granted money to Monroe County in Florida for the Two-Eyes Intelligence Project which enables field deputies to access a wide area network using desktop machines or laptop computers (42). To date, only 13 laptops are in use and each cost about \$9,000 to bring into operation. Each laptop utilizes a touch screen or pen-based screen and connections are made using either an UHF radio band or cellular digital packet data connections (CDPD). The CDPD has proven much faster than the UHF radio band. Each laptop has access to the Internet, the Miami-Dade Police Department network, and the Florida Criminal Information Center and National Criminal Information Center computer networks.

In 1998, the wide area network was put to the test as Hurricane Georges approached the Florida Keys and proved very successful. More deputies were put on patrol because of the evacuation, which meant too many users for the traditional law enforcement radio, which causes officers to have to wait turns to use the radio. The officers with the laptops, however, did not have to wait and helped relieve the backlog of radio users and lightened the dispatchers' load. Not only are the computers useful for coordinating officers during the evacuation and allowing access to dispatch databases, the laptops also proved useful after the hurricane had passed. Only residents were allowed back into the Keys to prevent looters and con-artists from swarming the area as they did in 1992 after Hurricane Andrew. The laptops were used to check the identification and automobile information of everybody wanting to return to the Keys.

HURRICANE EVACUATION GUIDELINES

The author developed the following guidelines to enhance and improve existing evacuation procedures currently in use. Not all guidelines can be applied by every agency. Many of them highly depend on location, the existing transportation network, and state policy. Funding and cost-benefit analysis also play a role in the process. The guidelines can be broken down into the following categories: Planning and

Preparation, Making the Evacuation Decision, Public Notification, Traffic Management During the Evacuation, and Preparation for the Future.

Planning and Preparation

1. *Develop Coordination Agreements* to establish a chain of command, lists of resources, and mutual-aid agreements.
2. *Use Equipment and Personnel Resource Lists* to keep tabs on available equipment and personnel and update the lists in real-time.
3. *Conduct Training* to adequately prepare personnel and volunteers. Conduct tabletop exercises as a part of the training to improve coordination and to pinpoint strengths and weaknesses.
4. *Plan Evacuation Routes* based on the demand, capacity, and clearance time for a particular region.
5. *Consider Phased Evacuation Plans* using both voluntary and mandatory evacuation orders starting with the most critical areas and moving inland.
6. *Conduct Transportation System Assessments* periodically and include temporary system conditions, such as construction activity.
7. *Plan for How to Deal with Construction Along Evacuation Routes* when construction is scheduled to take place on major evacuation routes during hurricane season. Where feasible, alternate evacuation routes may be developed and provided to the public. Detours around the construction area may also be planned in advance. If the evacuation route is needed despite the delay due to construction, the use of shoulders as temporary travel lanes might be considered with the aid of law enforcement direction.
8. *Plan for Use of Shelters* in case evacuation is not possible or is not mandatory.
9. *Conduct Public Awareness Campaigns* to encourage the public to pre-plan and to bring awareness to out-of-town visitors.

Making the Evacuation Decision

10. *Use Available Tools to Aid the Decision to Evacuate.* Examples of such tools include NOAA Weather Radio, EAS, SLOSH, EMWIN, and HURREVAC.
11. *Consider Use of a GIS-DBMS Model* to enhance evacuation operations by predicting the spatial and temporal characteristics of a region depending on the time of day an evacuation is issued.

Public Notification

12. *Use a Public Information Coordinator* who provides information to the media. Use law enforcement officers with sirens and public announcement systems as needed.
13. *Consider Use of a World Wide Web Site* that contains both general and real-time information.
14. *Consider Use of an Automated Public Information System* to provide a voice-mail telephone system to relay consistent and trusted messages to the public.
15. *Consider Use of Traveler Information Kiosks* at key places such as rest areas along evacuation routes.

Traffic Management During the Evacuation

16. *Operate an Emergency Operations Center* to coordinate all of the evacuation activities.
17. *Establish and Maintain Communications* among agencies. Use systems such as PIES in Texas and ESATCOM in Florida which have proven to be reliable. Have a back-up system available.
18. *Consider a Laptop Communications System* to help law enforcement personnel monitor the outgoing traffic and to respond quickly to incidents.
19. *Use Traffic Counters* to assess traffic flow and the volume of vehicles evacuating.
20. *Use Closed Circuit Television Cameras* to monitor traffic flow and to manage incidents.
21. *Use Channelizing Devices* as a part of traffic control.
22. *Use Static Signs* to provide general information. Consider the use of flip-down signs.
23. *Use Changeable Message Signs* to help convey timely and useful information.

24. *Use Lane Control Signals* in critical areas to help direct traffic.
25. *Use Highway Advisory Radio* to provide information pertaining to the weather, evacuation routes, incidents, and construction.
26. *Consider Vehicle Restrictions* for oversize cargoes and mobile homes.
27. *Adjust Signal Timings* to increase the green time and/or progression band for through movements leading out of an evacuation zone.
28. *Minimize Left-Turning Movements* along evacuation routes and on roads leading to evacuation routes.
29. *Promote HOV Lane Usage* to encourage motorists to evacuate in groups.
30. *Consider Reversible Flow* for short sections of roadways under extreme situations, such as the approach of a Category 4 or 5 hurricane with limited time to evacuate the public.
31. *Consider Suspension of Tolls* to encourage people to use toll roads, which in turn reduces bottlenecks at toll collection booths.
32. *Consider Use of a Bus System* to provide transportation for special needs members of the community (i.e., elderly, handicapped, etc.) and take them to shelters that provide special needs.
33. *Consider Tow Truck Usage* at key bottleneck locations along evacuation routes to help detect and clear minor accidents and help maintain traffic flow and capacity.

Preparation for the Future

34. *Develop a Database for In-Vehicle Computer Systems* that contains existing road networks and evacuation routes at a minimum. Include directions to shelter areas and alternate routes when construction takes place. Prepare to feed real-time information into the database when technicians develop a reliable communications system for delivering real-time information.
35. *Campaign to Install Automatic Vehicle Identification Tags in All Vehicles* so that traffic flow may be monitored during an evacuation and vehicles will be ready once technology has the capability to transmit messages through the AVI equipment.

CASE STUDY: GALVESTON, TEXAS

To illustrate an application of the evacuation guidelines presented in the previous section, the evacuation plans of Galveston, Texas were analyzed and the results are presented in this section. Galveston is located on a barrier island off of the coast of Texas, and Interstate Highway 45 (IH-45) is the only roadway that provides access to the island. The island is populated by approximately 60,000 inhabitants. An interview with William Zagorski, the Emergency Management Coordinator for the City of Galveston's Emergency Management Division (EMD), produced information about the practices in Galveston. The last evacuation conducted in Galveston was in 1989 for Hurricane Gilbert. Again, the state of Texas only issues voluntary evacuations. The current system in place has proved to be highly effective in the past. Although effective, no system is perfect and improvement is always possible.

Evaluation of Current Practices

Table 5 contains a summary of which evacuation practices recommended in the guidelines are used in the city of Galveston. Valid reasons exist for some of the practices not in use and improvements can be made to some of the practices already in use.

Validation of Practices Not in Use

Some of the practices not in use are not feasible for Galveston. The City of Galveston controls all activities on the island, and therefore, does not need formal agreements with other agencies. However, they do coordinate with the Galveston County Office of Emergency Management and Houston TranStar on an informal basis. Training is not currently a part of Galveston's EMD practices because personnel are continuously in action responding to various emergencies and activities such as tropical storms, flooding,

and island celebrations (i.e., Mardi Gras and Beach Party). Due to the small size of Galveston, evacuation route markers adequately mark evacuation routes and additional static signs are not needed. Lane control signals are not recommended because of the wind loading experienced during severe weather. Too few evacuations have been conducted to assess the feasibility of minimizing left-turning conflicts on evacuation routes. Although reversible flow has been considered on IH-45, it has been deemed impossible to implement because it requires more law enforcement officers than can be provided. No HOV lanes or toll roads exist, which eliminates the need to address them. Tow trucks have been used to clear disabled vehicles from bottleneck locations during special events but have never been used for hurricanes because of the danger placed upon the tow truck drivers.

Good Practices

Several exemplary practices are already in place in Galveston. These practices include the following:

- Extensive public awareness campaigns are conducted. Lectures are conducted at schools, the University of Texas Medical Branch (the island's largest employer), other large employers, and at other functions. Hurricane information is also presented at hotels to help keep tourists informed.
- Public notification is far-reaching. The Emergency Management Coordinator has access to the only cable provider on the island. He has the power to override all programming to alert the public of a recommended evacuation. Additionally, police cruise through assigned districts with public announcement systems to alert residents of an impending hurricane. Police are very familiar with their districts and even go door-to-door to alert the elderly and hard-of-hearing.
- As mentioned earlier, the Galveston area utilizes the Public Information Emergency System (PIES), which is a radio network that has proven itself reliable and effective.
- Although a few old mobile homes are left in Galveston, mobile homes are no longer allowed on the island because of their vulnerability to severe weather.

Recommendations for Galveston

The author recommends the following to enhance the existing hurricane evacuation procedures in Galveston:

- Plan for construction along IH-45;
- Consider the use of a GIS-DBMS model to aid traffic management;
- Update the City of Galveston Emergency Management Division web site by providing links to the Galveston County Evacuation Map, Houston TranStar's real-time traffic information, and the National Weather Service's Interactive Weather Information Network's real-time local weather ([43,44,45](#));
- Consider the use of traveler information kiosks at rest areas along IH-45;
- Consider obtaining a laptop communications system for local law enforcement personnel;
- Consider the development of a bus system to service the special needs population.
- Develop a database with stationary evacuation route maps for in-vehicle navigation computer systems and prepare the database for use in real-time for the future.
- Convince the residents of Galveston to install automatic vehicle identification tags in their vehicles

Table 5. Evacuation Practices Used in Galveston.

Evacuation Practice	Yes	No
Coordination Agreements		✘
Equipment/Personnel Resource Lists	✓	
Training and Tabletop Exercises		✘
Evacuation Route Plans	✓	
Phased Evacuation Plans	✓	
Periodic Transportation System Assessments	✓	
Plan for Shelter Use	✓	
Public Awareness Campaigns	✓	
Evacuation Decision Tools	✓	
Public Information Coordinator	✓	
World Wide Web Site	✓	
Automated Public Information System	✓	
Traveler Information Kiosks		✘
Emergency Operations Center	✓	
Intraagency Communication System	✓	
Traffic Counters	✓	
Closed Circuit Television Cameras	✓	
Channelizing Devices	✓	
Static Signs (other than Evacuation Route Markers)		✘
Changeable Message Signs	✓	
Lane Control Signals		✘
Highway Advisory Radio	✓	
Vehicle Restrictions (No Mobile Homes)	✓	
Signal Timing Adjustments	✓	
Minimal Left-Turning Movements		✘
HOV Lane Usage		✘
Reversible Flow		✘
Suspension of Tolls		✘
Tow Truck Usage		✘

CONCLUSIONS AND RECOMMENDATIONS

Due to the dangerous nature of hurricanes, emergency management agencies must continue to assess and improve hurricane evacuation plans. Successful plans help save lives by evacuating hurricane-prone areas in a timely and efficient manner. Currently, a multitude of hurricane evacuation procedures are in use or are being planned for use. All of the suggestions summarized in the Hurricane Evacuation Guidelines section should be considered for use by emergency management agencies. The feasibility of the guidelines presented will vary greatly by location, transportation network setup, cost, and hurricane frequency.

An analysis of Galveston, Texas illustrates that a solid evacuation plan is in place and that the City of Galveston has most areas of concern under control. Several minor suggestions were made toward the improvement of the Galveston evacuation process. All agency plans can use fine-tuning on a periodic basis.

Future Research Areas

As ITS technologies develop, emergency management agencies should include their possible use in the planning process. Geographic Information Systems and In-Vehicle Traveler Information Systems show promise for emergency management usage. Although these systems still have many obstacles to overcome, it is only a matter of time before all of the bugs are worked out. Emergency management agencies should be developing plans for integrating these ITS technologies into their emergency management plans, so that when the technologies do become fully developed, they will be ready for implementation.

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APPENDIX A: SAMPLE INTERVIEW QUESTIONS

- How frequently are hurricane evacuations conducted?
- What other transportation agencies are involved in the evacuation process?
- Do you conduct a training program to prepare for an evacuation?
- How is the public alerted that they must evacuate?
- How long does it typically take to evacuate the area?
- What types of devices/media/techniques are used in the evacuation process? (ie. static signs, variable message signs, radio, television, internet, wireless communication, lane control signals, closed circuit television cameras, in-vehicle navigation systems, one-way roadway operations, etc...)
- How reliable and effective are these devices and procedures?
- Are there any problems with the current process?
- If no constraints were present, how would you describe your ideal evacuation system?

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**SUITABILITY OF OPTICAL, RADIO AND RADAR TECHNOLOGIES
AS POTENTIAL EMERGENCY VEHICLE SIREN SYSTEM ENHANCEMENTS**

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SUMMARY

Emergency vehicle warning systems are used by police, fire and emergency medical services personnel to alert drivers sharing the roadway to yield the right-of-way to the approaching emergency vehicle. The warning to the drivers is given as a combination of visual and audible signals. The effectiveness of the siren system or audible signal is debatable. Some people believe the siren results in faster response times while others believe the siren is not significantly beneficial.

This paper presents an evaluation of the emergency siren system as an audible warning for passenger car drivers and investigates the suitability of optical, radio and radar technologies to enhance the current system. Basic knowledge of acoustics is required to evaluate the siren system. For a sound to be heard, the sound must be produced by a source, travel from the sound source to a receiver and the receiver must have the capability to perceive the sound. If any of the three components are missing, there is no sound. The details of the sound source, sound propagation, and the receiver are presented and discussed with respect to the emergency siren system.

Five criteria, identified as properties of a good audible warning system, are used to evaluate the emergency siren system. These criteria require that the siren be heard by the driver without being startling or disruptive. The siren must have meaning and must not harm the operator. The emergency siren system satisfies only two of the five evaluation criteria, which suggests that the audible signal used by the emergency siren system is inadequate.

When the passenger car is idling, the driver will likely hear the siren from up to 70 meters away. When the passenger car is traveling at a cruising speed of 70 mph (112 km/h), the driver may be able to hear the siren from up to 14 meters away. If the driver hears the siren when the emergency vehicle is very close, the siren will be loud, have a rapid onset and will startle the driver. The driver's attention may be shifted from driving to searching for the location of the emergency vehicle. This attention shift can be disruptive, and the driver may lose control of the vehicle.

The operators of the emergency siren are protected by the sound exposure limits published by the Occupational Safety and Health Association. If the guidance provided by the state driver manuals are indicative of the drivers' understanding of the emergency siren, each driver should have a general understanding of the required response to the approach of an emergency vehicle using emergency lights and siren.

A remedy for the deficiency of the siren system may include an enhancement of the sound source, or the sound receiver. Perhaps a different means of communication could be used. These alternatives are investigated.

Enhancing the sound source by increasing the sound output of the siren is not feasible. Alternatively, enhancing the sound receiver is feasible. There are several sound-based detection devices currently available which detect the siren and in turn notify the driver to the approach of the emergency vehicle.

Emergency vehicles have used sound, optical, radio and radar transmission for signal preemption or for the surveillance of speeding vehicles. The suitability of using an optical, radio or radar-based system is investigated. Considering the current system uses sound transmissions, the suitability of the other systems is based on a comparison with a sound-based system.

Optical, radio and radar-based systems have operating ranges greater than sound-based systems. The optical-based system provides no other benefit and is not able to warn pedestrians and other non-vehicle roadway users to the approach of an emergency vehicle. Both radio and radar-based systems provide additional benefits. Radio-based systems do not require the source to be in direct line of sight with the receiver and

radar-based systems have precise signal direction ability. Neither radio or radar transmissions are sensitive to weather. Therefore, the use of sound, radio, or radar transmissions is suitable when considering an enhancement to the current emergency siren system.

The author recommends the continued use of the siren system and the application of radio or radar transmissions as an enhancement. Study into the effectiveness of the siren system, with respect to response time is recommended for future study. As always, efforts to educate the operators of the emergency warning system and the drivers and the other roadway users should continue.

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INTRODUCTION

Emergency warning systems are used by police, fire and emergency medical services personnel to alert drivers sharing the roadway to yield the right-of-way to the approaching emergency vehicle. The warning is comprised of visual and audible signals, commonly referred to as lights and sirens.

The effectiveness of the emergency warning system is debatable. The National Highway Traffic Safety Administration supports the use of emergency warning systems and encourages drivers to take the sirens seriously. A brochure is available which describes how drivers can safely yield the right-of-way to an emergency vehicle(1). In contrast, in the April 1997 edition of the National Safety Council First Aid Newsletter, the American Academy of Orthopedic Surgeons was quoted as saying "the siren is probably the most overused piece of equipment on an ambulance. It does not really help other motorists in closed cars. Motorists driving at the speed limit with the windows rolled up, and the radio on and/or air conditioner or heater set on high, cannot hear the siren until the ambulance is only a short distance away. If the radio is particularly loud, the other driver may not hear the siren at all"(2). The newsletter also refers to a study conducted in North Carolina which found that ambulances using lights and sirens reached the hospital emergency department 43.5 seconds faster than those not using the emergency warning systems(2). Although the statements of the American Academy of Orthopedic Surgeons and the findings of the North Carolina study were limited to the use of lights and sirens on ambulances, they still suggest that emergency warning systems in general are not significantly effective.

Purpose

The purpose of this paper is to evaluate the emergency vehicle siren system as an audible warning for passenger car drivers and to determine whether optical, radio or radar transmissions should be used to enhance the siren system.

Scope

The emergency vehicle siren system is used to warn all types of drivers of all types of vehicles in a plethora of traffic and environmental conditions. The evaluation presented in this paper is limited to a passenger car driver, traveling directly in front of the emergency vehicle on a straight, level roadway. The siren is assumed to be a Class A siren capable of emitting a sound level of 120 dBA at 10 feet. Meteorological conditions and the effects of traffic, buildings, berms and barriers are neglected.

THE EMERGENCY SIREN SYSTEM

Emergency vehicles, such as police, fire and emergency medical services vehicles are permitted to have a siren. The purpose of the siren is to alert drivers of the approaching emergency vehicle. Upon hearing the emergency siren, each driver is expected to maneuver his or her vehicle to the right edge or curb of the roadway and stop. The driver should remain stopped until the emergency vehicle has passed, and it is safe to merge into traffic.

The siren system is a means of communication. Three main components of the emergency siren system must be present for the communication to be effective. The message must be created, relayed and received. In other words, the siren sound must be produced by the siren, travel through the atmosphere, and be perceived by the driver of the passenger car.

The source

The emergency siren is an electronic or electromechanical device for producing standardized acoustical signals.(3) The sound emitted by a signal propagates through the atmosphere as vibrational sound waves. The frequency and amplitude of the sound wave can be used to describe the perceived sound. The frequency is the measurement of the number of wave cycles occurring in a second and corresponds to the pitch of the sound. The frequency is expressed in cycles per second or hertz (Hz). The amplitude of the sound is a measurement of the height of the sound wave and corresponds to the sound intensity or loudness. The amplitude of the sound pressure P_1 is usually expressed in terms of the reference sound pressure (P_0). P_0 relates to the threshold of human hearing. This expression is shown below.

$$\text{Sound intensity (decibels)} = 20 \log (P_1/P_0) \dots\dots\dots \text{equation 1}$$

To provide a basis for comparison, the absolute sound intensity for some common sound sources are shown in Table 1. The sound intensity is relative to the threshold for human hearing. Therefore, a sound intensity of zero refers to a sound which is barely audible and does not mean there is no sound.

Different decibel scales can be used to measure the intensity of a sound. The A scale differentially weights sounds to reflect the characteristics of human hearing, providing greatest weighting at those frequencies where humans are most sensitive(4). A-weighted sound levels are most often used for estimating the effects of noise on people. For most transient sounds, such as a passenger car passing by, the A-weighted scale is preferred(5).

The Society of Automotive Engineers publishes the test procedures, requirements and the guidelines for the use of electronic and electromechanical emergency sirens. SAE J1849 recommends the minimum on-axis sound level produced by the emergency siren at $3.0 \text{ m} \pm 0.1 \text{ m}$ to be 118 dBA(3). The Federal Signal Corporation manufactures several models of sirens, amplifiers and speakers for emergency vehicle use. These systems have an on-axis sound output of approximately 120 dBA at 10 ft and comply with SAE J1849 and CCR, Title 13, Article 22 (Class A) requirements(6,7).

Table 1. Absolute Intensity of Some Common Sound Sources. (4)

Sound Level (dBA)	Common Sound Source
140	ear damage possible - jet at take-off
130	painful sound
120	propeller plane take-off
110	loud thunder
100	subway train
90	truck or bus
75	average passenger car; loud radio
60	normal conversation
50	quiet restaurant
40	quiet office; household sounds
20	whisper
0	threshold of hearing

There are three basic operation modes for a siren. The high-low mode produces a pattern of alternating high and low tones with a cycle rate of 40 to 60 cycles per minute. The wail mode produces a pattern of slow increases and decreases in frequency with a cycle rate of 15 to 30 cycles per minute. According to SAE J 1849, the frequency range should be greater than 850 Hz and lie within 650 and 2,000 Hz. The yelp mode is very similar to the wail mode except the cycle rate is 150 to 250 cycles per minute. The recommended frequency range is the same as the wail mode(3).

The mode of the siren does not affect the relative sound level at a distance from the siren. The frequency spectrum of the siren, whether in yelp, wail or high-low mode is essentially the same(8). Therefore, at any location from the siren, the relative sound level is independent of the mode of operation of the siren.

Sound transmission

As the sound wave travels through the atmosphere, from the source to the receiver, the intensity of the sound wave decreases. For a point source such as a siren, the drop-off rate of the intensity is approximately 6 dBA per doubling of distance. This relationship is referred to as the mean-square sound pressure and represents the geometric or spherical spread of the sound emanating from a single point source.

If the sound level (SL₁) in a particular direction from the source at a distance D₁ is known, the sound level at any distance (D₂) in the same direction can be calculated using the mean-square sound pressure equation:

$SL_2 = SL_1 + 10 \log_{10} (D_1/D_2)^2$ equation 2

If the distance of point 2 is farther from the source than point 1, the sound level at point 2 is lower than the sound level at point 1. This relationship is expected. The sound level you experience is strongest when you are near the source and weakens as you move away.

This equation does have limitations. When the siren emits a sound, the particles in the atmosphere are disrupted. Close to the siren the particles may not necessarily travel in the same direction as the sound wave. If measured with a sound measuring device, the sound levels would be greater than that expected by the mean-square sound pressure equation. Farther from the siren, the particles tend to move in the same direction of the sound wave. This area is considered the free space and the sound intensity is represented the mean-square sound pressure relationship.

Equation 2 does not account for the excess attenuation of the sound caused by geological and meteorological factors. The terrain, ground cover, foliage, berms and barriers as well as the air turbulence, temperature, wind gradients and precipitation affect the amplitude or loudness of the sound.

The receiver

The sound is the stimulus needed for human hearing. The healthy human auditory system is capable of perceiving sound frequencies between 20 Hz and 20,000 Hz, although it is most sensitive to frequencies between 1,000 and 5,000 Hz(4,9). The auditory system includes the outer, middle and inner ear. The outer ear captures the sound waves and funnels them into the middle ear. The sound waves are then amplified and conducted into the inner ear. The cochlea is located in the inner ear and contains the basilar membrane which translates the physical sound wave into electrical nerve energy. The auditory nerve then transmits this energy to the brain(4).

Some people experience hearing losses or the complete loss of hearing. The human auditory system can be damaged from exposures to loud sounds or long exposures to particular sounds. As people get older, they can experience a gradual decline in hearing capability. If the hearing loss is caused by a breakdown within the middle ear, hearing aids can be beneficial. The hearing aid can replace the function of the middle ear by

conducting and amplifying the sound wave. If the hearing is caused by a breakdown within the inner ear, hearing aids are not effective.

EVALUATION OF THE SIREN SYSTEM

To determine if the emergency vehicle siren system is a good audible warning for passenger car drivers, the siren must be evaluated. The author uses five criteria which have been identified as properties of a good warning system for use in a working environment(4). The use of these criteria is justified through a comparison of a worker in a workplace and a driver in a vehicle.

In the workplace, a worker is required to use tools to complete a task. A warning system alerts the worker of a particular situation requiring immediate attention. Similarly, a driver is required to use controls (steering wheel, accelerator, brake) to safely maneuver a vehicle. The emergency siren system alerts the driver of a particular situation which requires immediate attention. Since the task of driving has the same basic components of a workplace task, and the function of the warning system is the comparable to the function of the emergency siren system, the criteria used to evaluate a workplace warning system can be applied to the emergency siren system.

Evaluation criteria

The five criteria used to evaluate the emergency siren system are as follows:

1. The siren must be heard by the driver of the passenger car;
2. The sound level of the siren should not endanger the operator;
3. The siren should not be overly startling to the driver;
4. The siren should not disrupt the driver from maintaining control of the vehicle; and
5. The siren should have meaning for the driver.

Each of these criteria are discussed in the following sections.

The siren must be heard by the driver of the passenger car

To investigate whether the driver can hear the emergency siren, an analysis of the sound emanating from the siren is required. The analysis considers the source of the sound, the sound propagation, the sound transmission loss, and the resulting sound level perceived by the driver. In addition, competing sounds need to be discussed and compared to the sound level of the siren.

Sound level at the source. The Class A emergency siren emits sound pressures which measure 120 dBA on-axis at 10 feet, (3.084 m)(6,7) fulfilling the SAE J1849 requirements as published by the Society of Automotive Engineers(3).

Sound propagation. As the sound wave propagates through the atmosphere, the intensity of the wave is reduced. The reduction corresponds to the distance the wave has traveled such that a doubling of distance will result in a 6 dBA reduction in intensity. The upper line in Figure 1, labeled as the exterior siren sound level, represents the sound level of the siren within a range of 3m to 200 m from the siren.

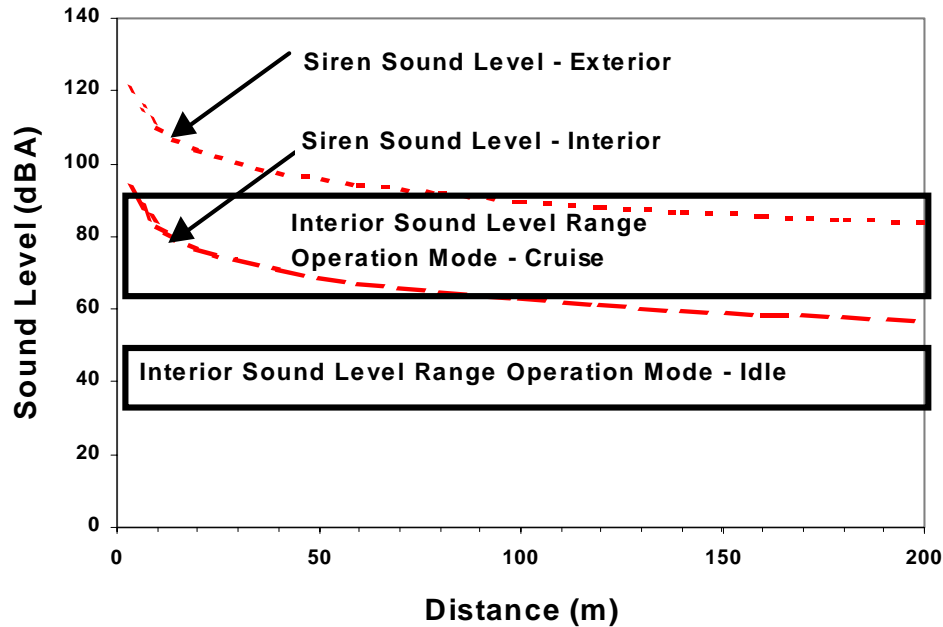


Figure 1. Siren sound levels and interior sound level ranges

The propagation of the sound wave can be affected by the environment. Meteorological factors such as temperature, humidity, precipitation and wind can cause fluctuations in the frequency spectrum of the sound wave. These factors are interrelated to some extent. Noise barriers, buildings, and other solid surfaces reflect the sound waves, and large areas of grass, shrubs or trees can absorb or dampen the sound waves.

Sound transmission loss. The exterior of the passenger car can be considered as a collection of sound reflective surfaces. When the person is seated in the drivers seat, their ears are in an area protected by the greenhouse of the vehicle. The greenhouse is comprised mainly of glass, which insulates the passenger compartment from noise.

The effectiveness of the glass depends on the type and thickness. A typical $\frac{1}{4}$ inch plane of safety glass can reduce the sound level by 27 dBA. In comparison, a $\frac{1}{4}$ inch 2 ply plane of laminated glass can reduce the sound by 34 dBA.⁽¹⁰⁾ As the thickness increases the sound reduction increases. By introducing layers of air or a laminating interlayer such as polyvinyl butyral, the effectiveness of the glass can be improved resulting in the increase of sound transmission loss.

The lower line in Figure 1, labeled as the interior siren sound level, represents the sound transmission loss associated with the typical $\frac{1}{4}$ inch safety glass. This type of glass is commonly used for side and rear windows and laminated glass is used for windshields, although some vehicle manufacturers are also using laminated glass in the side and rear windows.

Interior sound level. When a vehicle is in operation, the engine, transmission, tires, cooling fan, air inlet and exhaust create sounds and vibrations. The vibrational waves travel through the air and through the structure of the vehicle and combine to produce an ambient interior sound level. The sound level is dependent on the mode of operation. At low speeds, the engine sounds are the primary contributors. At high speeds the tire noise becomes more prevalent ⁽¹¹⁾.

Although there is no standard regarding the allowable sound level in the passenger compartment, automotive manufacturers regard the mitigation of these sounds as an important marketing concept. The quality of sound can be used to describe the quality of the vehicle and the comfort of the ride. Controlling the interior sound level also has functional considerations. Lower interior sound levels ease voice communication, decrease fatigue, reduce risk of hearing damage, and improve the ability to hear warning signals that originate outside of the vehicle(5).

In the 1999 Ultimate Comparison edition of the Road and Track magazine, interior sound levels were measured for different models of vehicles (12). A range of 35 dBA to 51 dBA was measured in 43 vehicles while the vehicles were idling. A range of 65 dBA to 93 dBA was measured in 182 vehicles while the vehicles were cruising at 70 mph. These interior sound level ranges are represented in Figure 1 and will be used to compare with the siren sound levels.

There are additional sound sources which can contribute to the interior sound level, such as compact disc players, tape players, radios, cellular phones, and air conditioners. Since the driver controls the operation of these systems and can easily turn them down or shut them off, these noise sources are not considered in the evaluation.

Masking. When two sound sources compete, one sound can hide or mask the other sound such that only one sound is perceived. For instance, if the radio is playing loudly, the driver may not notice the sound of the siren. This phenomenon is referred to as masking. To ensure the siren is perceived, it needs to be 15 dBA louder than the music being played on the radio (4).

Comparing the interior siren sound level to the ambient interior sound level. To account for the masking phenomenon, the interior sound level ranges presented on Figure 1 have been adjusted by 15 dBA and reproduced on Figure 2.

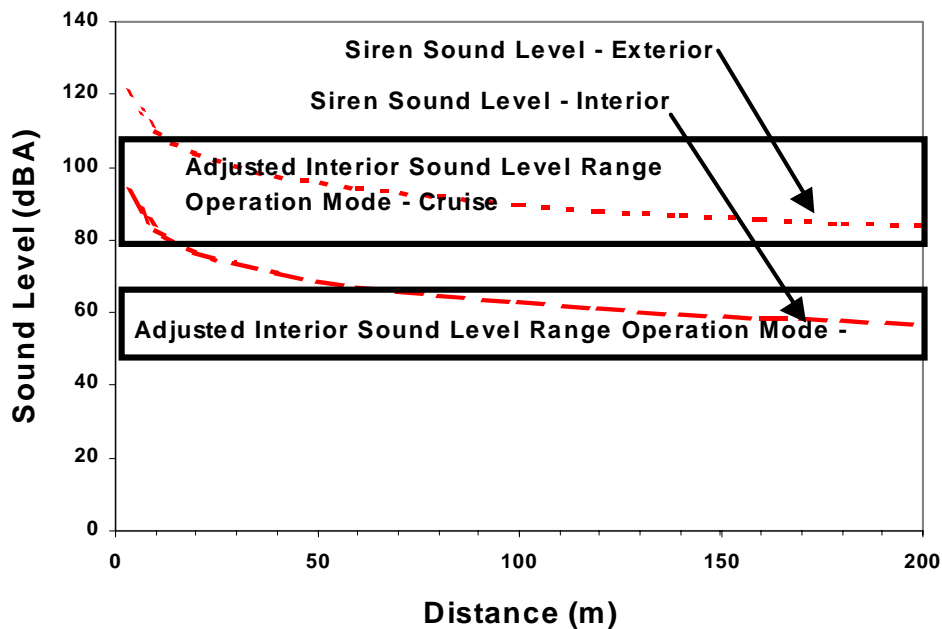


Figure 2. Adjusted interior sound level ranges.

By interpreting Figure 2, statements can be made regarding when the emergency siren can be heard. Within the adjusted interior sound level range for the idle mode, the area below the interior siren sound level line represents the conditions when the siren can be heard by the driver of the passenger car. Therefore, if the emergency vehicle is within 70 meters of a stopped passenger car, the driver of the car can most likely hear the siren. If the emergency vehicle is further than 70 meters, the driver of the car may be able to hear the siren.

Similarly, within the adjusted interior sound level range for the cruise mode, the area below the interior siren sound level line represents the conditions when the siren can be heard by the passenger car driver. This area is quite small. If the emergency vehicle is within 14 meters of a car traveling at 70 mph (112 km/h), there is a possibility that the driver can hear the siren.

Factors affecting response. Some drivers have permanent sensory impairments which affect their ability to perceive the emergency siren. Others drivers suffer from temporary impairments. Sleepiness, inattention, emotional state, intoxication, or the influence of drugs can affect a person's ability to perceive and respond to the emergency siren (13).

The response to the sound is not only dependent on the capabilities of the auditory system but also on the attitudes, memory and expectation of the human (14). The message may be perceived as unimportant or not requiring a response. The inappropriate use of the emergency siren may lead the driver to believe the siren is not important and can be ignored. If the message is not familiar, the driver may not be able to recall what the appropriate action is to take. The driver may have forgotten what to do when or may lack the knowledge of the appropriate response. It is also possible that the driver believes the siren has importance and recalls the appropriate response but performs another action. This action may be influenced by the driver's anticipation of the actions of the emergency vehicle.

The sound level of the siren should not endanger the operator

Long or repeated exposure to high sound levels can cause damage to the human auditory system. The Occupational Safety and Health Administration (OSHA) provides protection for workers by regulating the acceptable noise exposure. For instance OSHA limits the exposure of a 90 dBA continuous sound to eight hours.(4) If the exposure is greater, hearing protection is required to ensure hearing damage does not occur.

The siren should not be overly startling to the driver

When a person is startled by a loud, unexpected sound, several involuntary reactions occur. The person experiences a tightening of the muscles and a temporary increase in heart rate and blood pressure. As the person tries to appraise the situation a brief period of disorientation occurs. Once the threat passes or the person responds to the situation, the disorientation subsides and the muscles begin to relax. This is referred to as the acoustic startle effect. The strength of the acoustic startle effect is determined by the familiarity, loudness and the speed of onset of the sound, and the preparedness of the driver (14).

Just how familiar a driver is with the sound of an emergency siren is probably dependent on the frequency of exposure. It is reasonable to assume that the more times the sound is experienced the more quickly it can be distinguished. The preparedness of the driver is likely related to the driver's knowledge about the area. If the driver knows the road which he is traveling on is the major route for emergency vehicles, he is likely to expect to hear a siren. If he is traveling on a country road, the expectation of hearing a siren is probably quite low.

As the emergency vehicle approaches a passenger car, the siren gradually increases in intensity with respect to the drivers' position. If the driver is unable to hear the siren until the emergency vehicle has become quite

close, the sudden onset may startle the driver, and the threat will require an immediate response. The disorientation experienced by the driver may contribute to an inappropriate response.

The siren should not disrupt the driver from maintaining control of the vehicle

If the siren is disruptive, the driver's ability to process other signals will be affected. The driver will feel overloaded and will involuntarily neglect information. If the information is important, such as the position of other vehicles, a collision could result. However, the same result could be a manifestation of the effectiveness of an individual's driving behavior.

The March, 1998 edition of the Human Factors journal included an article about the factors that influence response times to audible stimuli. In three separate experiments, participants were required to respond to sounds emanating from different locations. Wallace and Fisher concluded that the participants were quicker to respond to sounds which emanated from a location directly in front of the participant position. The response times increased as the information content of the auditory stimulus became more complex (15).

The emergency siren is complex. It can emanate from any direction with respect to the driver of a passenger car. The siren can emanate from behind, in front, or to either side of the driver. Perhaps, the complexity of the siren disrupts the driver from maintaining control of the vehicle as the driver's attention becomes focused on identifying the location of the emergency vehicle.

The siren should have meaning for the driver

To evaluate whether drivers understand the meaning of the siren, the author reviewed the driver manuals from the 50 U.S. states. The author assumes the direction provided by these manuals are indicative of a driver's knowledge of the required actions with respect to emergency sirens.

In each of the 50 U.S. state manuals, there is a section containing the expected response of a passenger car driver upon the approach of an emergency vehicle whose lights and siren are in operation. All of the driver manuals instruct the driver to maneuver his or her vehicle to the side of the roadway.

Several inconsistencies were noted during the review of the driver manuals. Thirty-one state manuals specifically stated that the driver should not block the intersection. The remaining 19 manuals did not provide any details about clearing the intersection.

Thirty-three state manuals specified that the driver must yield regardless of the direction of the emergency vehicle. The Minnesota driver manual specifies for an emergency approaching from behind. The remaining manuals use general terms, such as "approaching" and do not specify direction.

Forty-nine state manuals direct the driver to pull over to the right and the Idaho manual specifies that the driver should pull over to the right side of the road where it is legal to park.

In addition, the Hawaii and Minnesota state manuals included don't panic statements and the Arizona and Indiana manuals included a statement about being alert and keeping the radio low.

Evaluation findings

In the evaluation of the siren as an audible warning for passenger car drivers, the author considered the driver of a passenger car, traveling directly in front of the emergency vehicle on a straight, level roadway. The siren was assumed to be a Class A siren, capable of emitting a sound level of 120 dBA at 10 feet. The effects of unimpeded sound propagation, and the sound dampening properties of the passenger vehicle were discussed.

Meteorological factors and the effects of traffic, buildings, berms and barriers on the propagation of the sound wave were not considered.

Five criteria, identified as properties of a good audible warning system, were used to evaluate the emergency siren system. These criteria require that the siren be heard by the driver without being startling or disruptive. And that the siren must have meaning and must not harm the operator. The findings of the evaluation are summarized in Table 2.

Table 2. Summary of evaluation findings

Evaluation criteria	Does the siren satisfy the criteria?
The siren must be heard by the driver of the passenger car	Sometimes
The sound level of the siren should not endanger the operator	Yes
The siren should not be overly startling to the driver	Sometimes
The siren should not disrupt the driver from maintaining control of the vehicle	Sometimes
The siren should have meaning for the driver	Yes

Evaluation results

Only two of the five criteria are satisfied by the siren system. The operator is protected from the sound level of the siren by the exposure limits published by the Occupational Safety and Health Association. A review of 50 state manuals suggests that the siren should be understood by drivers. The remaining three criteria are related to the sound level of the siren and when the sound is perceived by a driver.

When a passenger car is at rest, it is likely that the driver can hear the siren from 70 meters away. Beyond 70 meters the driver may hear the siren, depending on the ambient sound level inside the vehicle. When the passenger car is traveling at 70 mph (112 km/h), the driver may be able to hear the siren from 14 meters away.

The evaluation considered only one particular situation. It was shown that even in such a limited situation the siren would not be heard by all types of drivers, in all types of passenger cars. The siren may be overly startling or disrupt the driver from maintaining control of the vehicle. It is concluded that the emergency siren system is deficient as an audible warning for passenger car drivers.

ENHANCEMENTS TO THE EMERGENCY SIREN SYSTEM

A remedy for the deficiency of the emergency siren system may include an enhancement of the sound source, or the sound receiver. Perhaps a different means of communication could be explored. These potential remedies will be discussed in the following sections.

Enhance the sound source

Increasing the sound level output of the siren would most likely increase the occurrence of the siren being heard. More drivers would hear the siren from farther distances. Unfortunately, this simple approach to remedy the deficiency of the siren system has several major drawbacks. An increase in the siren output level could potentially endanger the operator. At current operating sound output, the siren can startle and/or disrupt a passenger car driver. Should the siren become louder, drivers may experience the startle effect more often and with greater severity. Simply increasing the sound level output of the siren would not remedy the present deficiencies of the emergency siren system.

Enhance the sound receiver

Alternately, the receiver could be enhanced. Instead of relying on the driver's ability to detect the siren, an artificially intelligent receiver could detect the sound of the siren and in turn notify the driver to the approach of the emergency vehicle. There are several sound-based detection devices currently available, which are typically used by the hard of hearing and the deaf. The device is installed inside the vehicle. When it detects the siren sound it provides either an amplification of the siren or a visual cue such as a flashing red light. Recognizing the needs of those suffering with hearing loss, General Motors uses its mobility fund to provide siren detectors. These detectors are small units mounted to the dashboard. A flashing red light warns the driver that an emergency vehicle is near (16).

Means of communication

Emergency vehicles have used sound, optical, radio and radar transmissions either for signal preemption or for the surveillance of speeding vehicles. Such technology may be suitable in enhancing the siren system.

Sound transmissions

Sound-based technology has been used for signal preemption systems. The sound of the siren is detected by a receiver connected to the signal controller. These systems have been found to have a short operating range of approximately 1200 feet (17). The detection is dependent on the strength of the sound signal and is sensitive to ambient noise (18). Meteorological conditions can influence the propagation of the sound waves thereby limiting the use of sound-based technology. Physical barriers such as buildings, berms, and trees can obstruct the sound wave, thereby requiring the source and the receiver to have a direct line of sight.

Light and strobe transmissions

Light and strobe-based technology have been applied to signal preemption systems. An infrared, visual light, or xenon light is transmitted from the emergency vehicle and detected by a receiver connected to the signal controller. These systems have been found to have an operating range of approximately 2500 feet (19). The detection of the optical signal is based on the strength of the signal. It is influenced by meteorological conditions and requires that the source be in direct line of sight with the receiver (18). The accuracy of the signal is imprecise. Other light sources can interfere with the system and cause false detection.

One-way radio transmissions

The radio-based preemption systems use a one-way radio communication from the emergency vehicle to a receiver connected to the signal controller. Although this technology is not influenced by weather conditions, and does not require the source to be in direct line of sight with the receiver, the detection of the radio signal is still dependent on the signal strength. The operating range of approximately 3500 feet, is reduced when the signal is obstructed by objects such as buildings (18). The focus of the radio signal is imprecise. All detectors within the operating range will receive the signal.

Radar transmissions

Traditionally radar and laser technology used by emergency personnel has been aimed at detecting vehicles exceeding the posted speed limit of the roadway. This technology is now being used to alert drivers to the approach of emergency vehicles. There are two companies which applied the radar and laser technology for this new use.

Cobra Electronics Corporation has developed Safety Alert, a radar-based detection system. The transmitter is designed to be linked to the operation of the emergency vehicle's light system. When the emergency lights are on, the Safety Alert system transmits a radar signal. Older radar detectors can receive the signal and alert the driver by means of an LED display and tone. A new generation of radar detectors can also receive text messages. There are three different messages which may be transmitted, one for an approaching emergency vehicle, another for a road hazard and a the third message to warn of an approaching train. This system has a range of $\frac{3}{4}$ mile (20).

The Radio Association Defending Airwave Rights, Inc. conceived the concept of the Safety Warning System (SWS), another radar-based warning system. Through assistance from industry partners and the Georgia Tech Research Institute, SWS was developed. SWS is referred to as " the most technologically advanced FCC approved system of its kind" (21).

The Safety Warning System uses a transmitter to emit a radar signal which can be detected by both traditional radar detectors and the new SWS-aware radar detectors. The transmitter can be used in police, fire, and emergency medical services vehicles, but are not limited to such use. It is designed to operate at from both a moving vehicle and a stationary location. It can be mounted in conjunction with changeable text message boards and even be linked to traffic management centers. The signal has a range of 1 $\frac{1}{2}$ miles and transmitters are presently in use in 33 U.S. states by transportation departments, police, sheriff and fire departments, and emergency medical units.

When a traditional radar detector receives the SWS signal, it warns the driver by means of an LED display and a tone. The SWS-aware detectors feature text messaging and synthesized voice messaging in addition to the traditional display and tone. There are over 60 messages reserved for highway construction and maintenance, highway hazard zone advisory, weather related hazards, travel information/convenience, and fast/slow moving vehicles. The system distinguishes between a stationary police vehicle, a stationary emergency vehicle, an emergency vehicle in transit, and a police vehicle in pursuit (21).

Additional consideration

When evaluating potential enhancements of the siren system, the ability to warn non-vehicle roadway users must be considered. The current siren system, which produces an audible signal, not only warns vehicle drivers of the approaching emergency vehicles but also warns non-vehicle roadway users such as pedestrians and bicyclists. Optical, radio and radar-based systems do not have the ability to warn non-vehicle roadway users.

Enhancement summary

Optical, radio or radar transmissions may be used to enhance the existing emergency siren system. Table 3 highlights the operating characteristics of the technologies used by emergency vehicles for signal preemption and the surveillance of speeding vehicles.

Table 3. Summary of operating characteristics

Characteristic	Type of Transmission			
	Sound	Optical	Radio	Radar
Operating range	1200 ft	2500 ft	3500 ft	3/4 to 1 ½ miles
Sensitive to signal strength	Yes	Yes	Yes	Yes
Requires line of sight	Yes	Yes	No	Yes
Precise signal direction	No	No	No	Yes
Weather sensitive	Yes	Yes	No	No
Sound sensitive	Yes	No	No	No
Light sensitive	No	Yes	No	No
Warns drivers	Yes	Yes	Yes	Yes
Warns pedestrians	Yes	No	No	No

Enhancement findings

The current emergency siren system is a sound-based system. To determine the suitability of the alternate means of communication as potential remedies of the siren system deficiencies, the characteristics of the optical, radio and radar-based systems are compared to the characteristics of a sound-based system. The use of an alternate means of communication must provide an additional benefit to be considered an improvement or enhancement of the existing siren system.

Sound-base systems have a unique quality. Such systems are able to warn drivers, pedestrians, cyclists and other potential roadway user groups. No other technology presented above is capable of warning roadway users other than vehicles drivers.

Although, optical-based systems have an operating range more than double that of sound-based systems, both systems require that the source be in direct line of sight with the receiver. These systems are weather sensitive and the receivers are dependent on the strength of the signal. Optical-based systems do not provide any benefit not already provided by sound-based systems.

Radio-based systems have an operating range almost three times that of sound-based systems. Unlike sound-based systems, radio-based systems do not require a direct line of sight between the source and the receiver and are not affected by weather conditions.

Radar-based systems have a few advantages over sound-based systems. Radar-based systems are not affected by weather and have much greater operating ranges. The radar signal can be directed with some precision unlike sound signals.

Enhancement results

Since the current emergency vehicle siren system uses sound transmissions for communication, the alternate means of communication were evaluated through a comparison of operating characteristic with those of sound-based systems. The use of an alternate type of transmission must provide an additional benefit to be

considered suitable as an enhancement of the existing siren system. The benefits and shortcomings of the transmission types are summarized in Table 4.

Table 4. Summary of the benefits and shortcomings of the transmission types.

Transportation Types	Benefits	Shortcomings
Optical transmissions	Greater operating range Not sensitive to ambient sound	Cannot warn pedestrians Sensitive to light sources
Radio transmissions	Greater operating range Not sensitive to weather Not sensitive to ambient sound Does not require line of sight	Cannot warn pedestrians
Radar transmissions	Greater operating range Not sensitive to weather Not sensitive to ambient sound Signal direction is precise	Cannot warn pedestrians

Although the use optical transmissions will provide additional benefit, its suitability as an enhancement of the existing emergency siren system is outweighed by its shortcomings. Therefore, the author feels that the use of optical transmissions should not be considered as a potential enhancement of the existing siren system. The operation of the emergency siren system would benefit from the inclusion of either radio or radar transmissions. These technologies must be used as enhancements and not as replacements, otherwise the ability to warn pedestrians and other non-vehicle roadway users would be lost.

RECOMMENDATIONS

Although the emergency vehicle siren system was found to meet only two of the five evaluation criteria, this system has the unique ability to warn not only vehicle drivers but also pedestrians and other non-vehicle roadway users. Systems which use means of communication other than sound transmission do not exhibit this characteristic. Therefore, maintaining the use of the emergency vehicle siren system is recommended.

A comparison of alternate means of communication was made. Optical-based systems do not exhibit characteristics beyond that of sound-based systems with the exception of the operating range. Optical technology is not recommended as an enhancement as it does not remedy the deficiency of the emergency siren system.

Radio and radar-based systems provide greater operating ranges and are not sensitive to weather conditions. Radio transmissions do not require line of sight and do not have specific signal direction. Radar transmissions required broad line of sight but the signal is direction specific. Both of these alternate means of communication provide benefits not provided by sound-based systems. Although these systems are not able to warn pedestrians and other non-vehicle roadway users, they are recommended as enhancements to remedy the deficiency of the current emergency siren system.

This research paper was limited to the evaluation of the emergency siren system as an audible warning system for passenger car drivers. The effectiveness of the emergency siren in reducing the response time of emergency vehicles was not evaluated. Such an evaluation is recommended for future study.

Evaluation criteria 5 stated that the siren must have meaning. The author assumed that the information in the 50 U.S. state driving manuals was indicative of drivers knowledge, it is possible that the driver understanding associated with the emergency siren system is slightly different. It is also possible that driver reaction to the siren is inconsistent with driver understanding due to the startle effect. This is an area that requires future investigation.

To ensure drivers understand the meaning of the emergency siren and to give the driver the confidence to act appropriately, continued driver training is required. To ensure the siren has a consistent meaning, operator training is essential.

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**APPLICATION OF AUTOMATED ENFORCEMENT FOR
HIGHWAY-RAILROAD GRADE CROSSINGS**

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SUMMARY

With the hundreds of thousands of highway-railroad grade crossings in the U.S., it is impossible, both from a standpoint of funds and practicality, to enforce violation laws with traditional methods. Several techniques which utilize state-of-the-art technology have been developed to solve this problem. These enhancements to highway-railroad grade crossings could be used at locations with the largest traffic and train volumes. Automated enforcement is one of these enhancements that could prove to be extremely valuable.

Automated enforcement typically consists of detection equipment and cameras to capture images of drivers violating the law. New York City and Los Angeles were among the first locations in the U.S. to use this type of law enforcement. After the favorable results that these programs produced, other areas such as San Francisco, California; Howard County, Maryland; Jonesboro, Arkansas; and Ames, Iowa have initiated automated enforcement programs of their own. These programs are ideal for examination in the installation of new automated enforcement systems.

The primary objectives of this paper were to evaluate the use of automated enforcement at railroad crossings already in place in the United States, including the observed results in both safety and public acceptance; examine the automated enforcement products, such as sensors and cameras, now available, including their cost and capabilities; identify the concerns of railroad companies in regard to automated enforcement; apply the principles and data gathered to develop a procedure for installing an automated enforcement system; and formulate an automated enforcement system for a highway-railroad grade crossing in College Station, TX.

These objectives were accomplished by performing a literature review on the issues involved with accidents and violations at highway-railroad grade crossings. In addition, telephone conversations were conducted with officials involved with automated enforcement programs in the U.S.

Based on the research, the six following guidelines were formulated to follow in the implementation of an automated enforcement program:

- Review applications in the U.S.;
- Establish good relations with the public;
- Purchase equipment;
- Install system;
- Execute trial runs; and
- Evaluate and modify.

All officials that were contacted for this report expressed confidence that automated enforcement could become an extremely valuable tool in the future of law enforcement. However, in comparison with other transportation technologies and advances, automated enforcement is still relatively new. It was concluded that additional research and study are needed to identify problems and their corresponding answers concerning this technology.

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INTRODUCTION

Automated enforcement typically consists of detection equipment and cameras, either 35-mm or digital models, to capture images of drivers violating the law. This method of law enforcement has been in use in some form in the United States since the 1980s. The most popular applications of automated enforcement (AE) are for violations of traffic signals, HOV and bus lanes, speed limits, highway-railroad grade crossings, and electronic toll collection (*1*).

The applications that have undergone the most studying and testing are for violations of traffic lights and highway-railroad grade crossings. Large cities such as New York City and Los Angeles were at the forefront of the use of AE, mostly due to their agencies' ability to fund the programs (*2*). Because of the success these two agencies have had, automated enforcement has been expanded to several other cities such as San Francisco; Howard County, Maryland; Jonesboro, Arkansas, and Ames, Iowa. Other states have had agencies conduct studies and tests using automated enforcement for these two applications, but have held off implementing it the programs until legal questions have been answered. Table 1 summarizes the use of AE for traffic signals and highway-railroad grade crossings.

Table 1. Automated Enforcement Programs in Operation and Demonstration Projects of Traffic Signals and Highway-Railroad Grade Crossings (*2*)

Application Types	Traffic Signals	Highway-Railroad Grade Crossings
Programs in Operation	Oxnard, CA San Francisco, CA Howard County, MD New York City, NY Victoria, Australia	Jonesboro, AR Los Angeles, CA Ames, IA
Demonstration Projects	Polk County, FL Jackson, MI Lincoln, NE	Norfolk Southern Corporation, NC Department of Transportation, TX Miami, OK

AE at traffic signals, where a violation occurs when a vehicle crosses the stop bar after the traffic signal has changed to the red phase, has been the application that has been tested and studied the most (*2*). As of December 1998, AE systems have been installed at over 130 intersections in Victoria, Australia, and at nearly 50 intersections in the United States. The Netherlands has also used AE for this purpose.

Violations at highway-railroad grade crossings occur when a vehicle is driven around, under, or through a crossing gate that is closed, or is in the process of being raised or lowered (*3*). AE for highway-railroad grade crossings has been in place in three areas in the United States: Los Angeles, California; Jonesboro, Arkansas; and Ames, Iowa. AE has also been extensively tested by several state agencies.

Highway-railroad grade crossings can use either an active or passive warning system. Active warning systems use flashing lights or signals, bells, and lowering gates to convey the message that a train is approaching to drivers. A passive warning system, on the other hand, does not feature any of these. Since a passive system will typically be in a location with a low amount of traffic and train volume, the drivers will use the sight distance provided to watch for an oncoming train (*1*).

In the past few years, several tragic accidents have occurred at highway-railroad grade crossings in the U.S. which have made the national news and attracted public attention. These collisions between trains and vehicles usually result in serious injury or death for the vehicle operator, and always cause extensive property damage. Some accidents have also resulted in the loss of life for passengers on trains that have derailed after the collision (4). The fact that a collision between a train and a vehicle contains a high amount of potential for injury and loss of life is evidence that steps must be taken to increase the safety at highway-railroad grade crossings.

The traditional method for a violator of a highway-railroad grade crossing to be ticketed was if a nearby police officer saw them. The number of crossings that have histories of violations makes the deployment of an officer at each crossing both economically infeasible and impossible in regards to the limited resources at a police department's disposal. Even if this plan could be implemented, the police presence might cause distractions along the roadway (5). Therefore, an enforcement plan must be both cost-friendly to the tax-paying public and keep the intrusion on the natural traffic flow as low as possible. Such a plan could be used on railroad crossings that experience the highest volume of traffic and/or observed violations. AE has the potential to fulfill these requirements. Further testing is required to determine if this potential can be realized.

There are two reasons why enforcement systems such as AE have first been installed at highway-railroad grade crossings with active warning systems. The first reason is that active warning systems typically operate in areas where both train and vehicle volumes are high and the necessary funds are available to install these types of warning systems. Conversely, passive warning systems remain in place at highway-railroad grade crossings for one of two scenarios: (1) The crossing does not have a history of accidents, or (2) The crossing is maintained by agencies that do not have the resources to upgrade it to an active warning system. The second reason is that highway-railroad grade crossings with passive warning systems tend to be in locations where power is not readily or easily available for advanced systems such as AE (6).

Research Objectives

The primary objectives of this paper were to:

- Evaluate the use of automated enforcement at highway-railroad grade crossings already in place in the United States, including the observed results in both safety and public acceptance;
- Examine the automated enforcement products, sensors and cameras, now available, including their costs and capabilities;
- Identify the concerns of railroad companies in regard to automated enforcement;
- Apply the principles and data gathered to develop a procedure for installing an automated enforcement system at a highway-railroad grade crossing; and
- Formulate an AE system for a highway-railroad grade crossing in College Station, TX.

Study Approach

The objectives of this paper were accomplished with several methods. Literature was reviewed regarding the recent history of accidents at highway-railroad grade crossings and the types of motorist violations that have caused them. Enforcement efforts to curtail these violations were identified. The components of an AE system were discussed, including what products currently exist.

Locations that have used AE for highway-railroad grade crossings were identified. Information concerning the accident problems that these crossings experienced was acquired, as were the results of having the AE system in place. Officials involved in the AE systems were contacted, and their opinions and the information pertaining to the crossings was analyzed. Guidelines for installing an AE system were then prepared.

Study Scope

The scope of this paper was limited to highway-railroad grade crossings that have active warning devices. While violations of both active and passive warning systems can lead to accidents, active warning systems were chosen as the focus for reasons mentioned in the Introduction. Further research is needed on identifying techniques that improve safety at highway-railroad grade crossings with passive warning systems.

Organization of the Report

Following the introduction, this research report is divided into six sections. The first section contains an overview of the recent history of accidents at highway-railroad grade crossings. In addition, the violations that caused these collisions and enforcement efforts are discussed. The following section is composed of a review and summary of the types of AE products and technology that are presently available. Following the technology section is a detailed account of the locations in the United States that either have an AE program in place, or have conducted tests or demonstrations with AE. The following section contains a summary of discussions that were made between the author and officials at three of these locations. The next section includes a discussion of the general procedures that must be done to install an AE system. After the procedures section, recommendations are made regarding the application of an AE system to a highway-railroad grade crossing in College Station, Texas. Finally, there are conclusions based on the previous sections.

VIOLATIONS OF HIGHWAY-RAILROAD GRADE CROSSINGS

Accident History

Highway-railroad grade crossings have been locations of accidents for decades. The statistics indicate a disturbing trend. In the U.S., a collision between a train and a vehicle or pedestrian occurs every 100 minutes (4). If only vehicles are included in these collisions with trains, the frequency of an occurrence is once every 90 minutes. These collisions occur on the 280,000 highway-railroad grade crossings, which are either publicly or privately owned (7). While the number of collisions at highway-railroad grade crossings has decreased steadily over the last eighteen years (Table 2), the number of fatalities these collisions have caused has decreased at a much slower rate.

Table 2 indicates that the number of collisions at crossings has decreased from 9295 in 1981 to 3446 in 1998, or a reduction of nearly 63 percent. During this time frame, the number of fatalities at these crossings has decreased from 728 to 422, a reduction of only 42 percent. The fact that the number of collisions has fallen could be attributed to several reasons. First, significant improvement has been made over the last two decades in the quality and quantity of advance warnings that are provided for drivers approaching highway-railroad grade crossings. The Highway Safety Act and the Federal Railroad Safety Act of 1970 initialized procedures and allocated federal expenditures for safety improvements at highway-railroad grade crossings. More than 25,000 improvement projects resulted from this Act, which have saved an estimated 6,400 lives (8). Second, public awareness has been heightened with the use of television commercials, educational literature, and the media attention given to previous accidents. The number of highway-railroad grade crossings might have also decreased due to railroad deregulation (6).

While the numbers of collisions and fatalities have decreased, a closer examination of the data reveals a growing problem. The number of fatalities per collision has risen from 0.078 in 1981 to 0.122 in 1998, an increase of over 50 percent. Furthermore, the increase was relatively steady from 1981 until 1989, where the number remained near 0.12 fatalities per collision in the following years (4). It is the opinion of the author that three conclusions can be drawn from this trend.

Table 2. National Highway-Rail Grade Incidents at Public and Private Crossings for All Highway Users (4)

Year	Collisions	Fatalities	Number of Fatalities per Collision
1998	3446	422	0.122
1997	3865	461	0.119
1996	4257	488	0.115
1995	4633	579	0.125
1994	4979	615	0.124
1993	4892	626	0.128
1992	4910	579	0.118
1991	5386	608	0.113
1990	5713	698	0.122
1989	6525	801	0.123
1988	6615	689	0.104
1987	6391	624	0.098
1986	6396	616	0.096
1985	6919	582	0.084
1984	7281	649	0.089
1983	7161	575	0.080
1982	7748	607	0.078
1981	9295	728	0.078

First, it is possible that the accidents that have been eliminated are not as severe as the accidents that are still occurring. A collision where a vehicle is driven into the side of a train at a crossing is not as severe as a collision where a train strikes a vehicle that is traveling across a crossing. With the upgrading of warning systems from passive to active, the likelihood of a vehicle being driven into the side of a train has decreased (4). Second, the overall average speed of trains might have increased. Researchers have found that the large size of a train causes it to appear to be traveling at a much slower speed to a driver. A driver can miscalculate the amount of time until the train arrives at the crossing. If the driver decides to violate the crossing, a collision with the train will be even more severe with the train's increased speed (9). Finally, there has been an increase in the percentage of small, compact cars on the road. The vehicles would not offer as much protection in the event of a collision as larger vehicles would (10). While these are potentially plausible reasons, they and their corresponding solutions lie outside the scope of this report.

In 1994, 53 percent of the 4,979 highway-railroad grade crossing accidents occurred at sites equipped with an active warning system. It has been estimated that 18 percent of the nation's highway-railroad grade crossings can be classified as using an active warning system (5). Therefore, even though active warning systems account for a small minority of the highway-railroad grade crossings, they are the location for a majority of the collisions. As was mentioned in this report's introduction, crossings with active warning systems typically experience a higher volume of train and traffic volume than crossings with passive warning systems. This higher volume leads to higher number of possible collisions. Studies can be conducted on the causes of these accidents because crossings with active warning systems are usually located in areas with agencies that can fund these activities.

Definition of Crossing Violations

The focus of this report was on highway-railroad grade crossings with active warning systems. To narrow the scope even further, only active warning systems with automatic gates was discussed. The methods of violating this type of active warning system are as follows (5):

- Driving under the gates as they are descending;
- Driving around the gates after they are in the horizontal position;
- Driving through the gates after they are in the horizontal position; and
- Driving under the gates as they are ascending.

These types of violations can lead directly to collisions that can result in injuries and fatalities for the occupants of both the train and the vehicle. It has been the responsibility of police departments to apprehend violators of highway-railroad grade crossings.

Traditional Enforcement Methods

Before AE and other recent advancements, the only way for a violator of a highway-railroad grade crossing to be ticketed was if a nearby police officer saw them. The police officer would make a traffic stop and issue a citation. Two problems stem from attempting to use this traffic stop technique exclusively.

First, the observing police officer must be able to pursue the violator to administer a traffic stop. If the officer is in the lane that is traveling in the opposite direction of the violator, this poses no problem. The officer can perform a U-turn maneuver and stop the violator. In this case, it is doubtful that a driver will commit a violation if an officer is in view in front of the driver. However, if the officer is traveling behind the driver in the same lane, the officer will also have to cross over the railroad tracks and through or between the gates to pursue the violator. This places the officer in an extremely dangerous position. In this case, it is not worth catching an offender for a fine if additional lives are placed in danger. Also, it is possible that the train will arrive before the violator can be pursued. Unless the officer has recorded the license plate number of the vehicle, it is nearly impossible to apprehend the violator.

To combat this potentially dangerous exposure to police, team enforcement has been attempted, which is the process of using multiple officers. One police officer is stationed near the highway-railroad grade crossing, usually in an unmarked vehicle. When a violation is observed, the officer radios a police officer downstream from the crossing with information about the vehicle. The second officer then apprehends the violator. Another team enforcement method that has been tried is called the "Trooper of the Train" plan. In this plan, a police officer who is equipped with a radio rides in the locomotive cab of a train. When the officer observes a crossing violation, the officer notifies another nearby police officer to stop the vehicle (10).

These methods eliminate the danger of exposure that would occur if an officer was to follow the violator through the crossing. However, this is an extremely costly use of resources for any police department, and few departments can continue using team enforcement for a long period of time (1).

The second problem with using traffic stop methods, both single officers and teams, is related to the large number of crossings. In 1997, approximately 225,000 public and 140,000 private highway-railroad grade crossings were in existence in the U.S. (5). Enforcement of these crossings would require a very large amount of officers, police vehicles, and time, and would be practically impossible. Even if only the crossings with the largest histories of violators are manned, they would still require a large amount of resources and time from the police departments. Also, much of the time spent at a crossing would be wasted due to the low frequency and unpredictability of violations. Also, if these traffic stop methods were implemented, the police presence might cause distractions along the roadway.

Furthermore, it is always possible that the violation will be challenged in court. For the violation to be upheld, the police officer would have to attend the trial, spending time which would be better served elsewhere. Also, there is always the chance that the violation will not be upheld by the court. Violations have been dismissed due to reasons such as the observing police officer not showing up for the trial, poor field notes being written about the violation, and lawyers being able to establish that the officer did not see if the crossing's warning system was operational (1). Therefore, an enforcement plan must be cost-friendly to the tax-paying public and keep the intrusion on the natural traffic flow as low as possible. Such a plan could be used on railroad crossings that experience the highest volume of traffic and/or observed violations.

Enhancements to Highway-Railroad Grade Crossings

Several new enhancement plans have been developed in recent years that are designed to prevent violations from occurring at highway-railroad grade crossings. A few of these enhancements are (5):

- Four-quadrant gates;
- Highway traffic signals;
- Raised medians; and
- Automated enforcement.

Four-quadrant gates are installed at highway-railroad grade crossings with active warning systems already in place. When the gates are in the horizontal position, both directions of roadway on both sides of the railroad tracks are blocked by the gates. This enhancement is designed to prevent violations of vehicles being driven around the gate arms. Four-quadrant gates do not, however, prevent violations where the vehicle is driven through the gates in the horizontal position or under the gates as they are ascending or descending (5).

The flashing red lights of a typical active warning system can be replaced with highway traffic signals. This method is based on the assumption that drivers will recognize and obey a traffic signal more often than they will a system of flashing red lights. However, this enhancement plan does not directly prevent the four violations of gate arms previously mentioned (5).

Another enhancement that can be used to prevent vehicles from traveling between gate arms in the horizontal position are raised medians. These barriers separate the opposing traffic lanes and keep vehicles from performing the zigzag maneuver. Like four-quadrant gates, however, raised medians can not prevent violations where a vehicle travels through the lowered gates or under the gate arms as they are ascending or descending. In addition, the construction work that is needed to install median barriers will cause disruptions to the normal flow of traffic (6).

While these three enhancements have the potential to be effective at enforcing highway-railroad grade crossings, each possesses a weakness that violators can exploit. Further testing must be carried out on each of the three enhancements before wide-spread implementation takes place.

Each of these three systems attempts to prevent the physical act of violating a highway-railroad grade crossing. Automated enforcement, on the other hand, is designed to enforce crossings by automatically recording the violation and enabling police officers to issue citations. The components of an AE system are identified in the following section.

TECHNOLOGY

Automated enforcement systems can record photographs of vehicles that commit violations at highway-railroad grade crossings. These photos can be used as evidence in issuing the violator a citation. This section contains an extensive review of how automated enforcement systems operate.

Many requirements need to be met by AE technology for an enforcement system to be effective. According to a 1996 article, AE technology must be capable of attaining the following ten qualities (11):

- Easily capture, transmit, process, store, and recover images;
- Provide resolution of the image that is extremely high in detail;
- Minimize the effect that overexposed portions (vehicle headlights and sunlight) have on the image as a whole;
- Provide a high amount of detail through the use of light and dark contrasting;
- Capture blur-free images of moving vehicles;
- Detect violations in varying levels of light (which occur at different times during the day);
- Eliminate sensor defects such as bright or dark columns on the image through the use of camera electronics such as image enhancement circuitry;
- Capture images at frame rate high enough to identify multiple vehicles committing violations;
- Possess installation flexibility so it can be mounted into permanent, temporary, and mobile settings; and
- Be constructed of materials that are environmentally friendly.

In addition, AE systems must be durable, cost-effective, and accurate.

AE technology will be exposed to the elements of nature. It must be able to operate in variable conditions such as rain, high wind, ice, and hot and cold temperatures. AE systems are also frequent targets of vandalism, especially in remote and economically depressed areas (6).

The AE system must be inexpensive enough to warrant the large capital cost that is required to install it. If the perceived benefits do not out-weigh the cost of purchasing and setting up the equipment, other methods of enforcement of highway-railroad grade crossings should be explored (2).

Finally, an AE system must be able to consistently provide accurate photographs that can be admissible in courts of law as evidence of a violation. It is a waste of time and resources if the system produces images from false alarms. If the photograph is taken either a second too soon or too late, it might be impossible to identify the violator (12). The components of an AE system must all work together efficiently to qualify the entire system a success.

Automated Enforcement Subsystems

AE systems are typically made up of three main subsystems: a violation detection subsystem, a violation-recording subsystem, and a central computer subsystem (12). The operations of the AE subsystems are described in the following paragraphs.

Violation Detection Subsystem

The violation detection subsystem can be of three different types: inductive loops, infrared beams, and video imaging cameras. All three types employ different technologies to accomplish the same basic task. Typically, the device is activated along with the active warning system components (gates, bells, and flashing red lights). This is accomplished by the violation detector subsystem being connected with the normal circuitry of the highway-railroad grade crossing. Either a singular detector or multiple detectors are used to cover both highway approaches. Both highway approaches must be covered so that the four types of

violations can be detected (12). After the train has passed and the features of the active warning system have ceased operation, the violation detection equipment will power down and remain in stand-by mode.

Violation Recording Subsystem

For a citation to be mailed to the violator, evidence of the violation is required, therefore each AE system features a violation recording subsystem. For a citation to be issued and upheld in court, there must be a photograph of the vehicle crossing the tracks while the crossing's warning system is active. The four products that will be later discussed feature the ability to capture two photographs of the violation. These photos or images are taken when the violation detection subsystem relays notification that a violation is taking place. The images must meet three requirements to be admissible in court (2):

- The license plate of the vehicle is visible and can be identified;
- The vehicle is shown to be committing one of the four types violations mentioned in the previous section; and
- The warning system of the crossing must be shown to be operating correctly.

The subsystem will typically imprint violation information such as location, time, and date on the image that is taken. Both violation detection and violation recording subsystems can be housed in or on structures such as controller cabinets and signal and sign poles. This characteristic is designed to provide safety from the elements and vandalism (12).

Citation Processing Subsystem

After the previous subsystems have obtained the evidence that is needed to cite a violator, equipment must be available that will store and process the photographs. Earlier AE systems kept the images stored in the housing structures that contained the violation recording devices. An officer would periodically stop at each crossing and retrieve the stored information. Newer systems have the ability to relay information from each crossing by way of telephone line, fiber-optic wire, or other advanced methods (13). The data can be sent to police departments for storage in a computer database.

In addition to the three requirements of images that were addressed in the previous paragraphs, the National Cooperative Highway Research Program Synthesis 219 identifies six requirements that must be met in order for a citation given through the use of AE to be acceptable (14).

- Identification of the date, time, and location of the violation;
- Existence of an enabling statute that meets the legal and constitutional standards of the courts;
- Periodic certification that the products meet the specifications set forth by the NHTSA and the corresponding state agency;
- Evidence that the instrument was working properly at the time of the offense;
- Proof that the operator/monitor of the AE instruments are properly trained; and
- Proof of the scientific reliability of the AE instrument.

If the police officers at the department can verify that these requirements have been met, they can continue with the process of issuing a citation. The officers can record the license plate number from the images, and match the vehicle with its owner. A computer database at the police department will contain information regarding the owners of registered vehicles. Citations can then be sent out to the car owners. Certain AE programs have allowed owners to identify the driver of the vehicle if they were not responsible for the violation. The citation is then sent by the police department to the driver responsible (2).

Available AE Products

Due to the fact that AE for highway-railroad grade crossings has only been installed in three locations in the U.S., and has been demonstrated by a few other states, there are a very limited number of results that can be analyzed with regard to the different product manufacturers. Therefore, the focus of this section will be on the four manufacturers whose products have been installed. The companies are American Traffic Systems, Econolite, SAIC, and US Public Technologies. Their corresponding products are the SafeTrax RC-200 Railroad Crossing Violation Camera, the AUTOSCOPE Video Vehicle Detection System, the Traffic Violator Grade Crossing Monitor, and the TRAXGUARD Automated Railroad Grade Crossing Enforcement System, respectively (1). These products will be discussed in detail, and other potential companies that produce technology which could be useful for railroad crossing AE will be identified.

American Traffic Systems - SafeTrax RC-200 Railroad Crossing Violation Camera

In regard to violation detection subsystem, SafeTrax offers a choice between standard inductive loops and piezoelectric sensors. Inductive loops are used for basic vehicle detection, without any special features. Piezoelectric sensors, however, have the ability to classify the vehicle based on its length and number of axles and measure the vehicle's speed. The violation recording subsystem will use this speed to determine when the second image is recorded. This feature of the sensors can also serve another purpose. In addition to violation data, SafeTrax can record traffic data for all vehicles. This data could be used in traffic studies and other transportation projects in the vicinity.

Both types of detectors are placed into the pavement between the warning gates and the railroad tracks, and across both lanes of each approach. This placement should detect the common act of violation where a vehicle travels around the gates, and the occasional violation where a vehicle travels through the gates.

The camera, which uses digital technology, imprints the time, date, and location of the violation, lane number, vehicle type, amount of time that the warning system has been active, and frame sequence numbers on the images it captures. There is also the option of including an integrated video monitoring system. This is used for 24-hour recording of a crossing with a history of violations in a day. Two SafeTrax cameras can also be installed in conjunction with each other at a crossing, for the purpose of obtaining photographs of both the front and rear of the violating vehicles. There are areas in the U.S. where many vehicles have license plates on one end (2).

SafeTrax relays the stored information through remote access. The system can be accessed by telephone line, cellular communication, fiber-optic wire, or satellite link (13). Power is supplied by a 110/220 volt battery. In case of an interruption of power, a backup battery maintains violation data for 30 days.

Econolite - AUTOSCOPE Video Vehicle Detection System

The AUTOSCOPE Video Vehicle Detection System is used in conjunction with cameras and a processing computer system. The computer system, or "supervisor" computer, is equipped with an AUTOSCOPE Supervisor Digitizer Board. In the application that will be discussed later in the report, these products were supplied by U.S. Public Technologies (15).

The AUTOSCOPE system can support up to four video cameras at each crossing. To set the areas of detection of a violation, a user can draw the detector shapes graphically on a video monitor with the use of a mouse. The graphical images of the detectors change colors when a vehicle crosses over them, providing a visual verification of the detection. Different types of detectors can be selected, and the placement of the detection zones is limited by the boundaries of the field of view of the cameras (12). Changing the locations of the detection areas involves redrawing the detector shapes on the screen. Once again, the probable

placement of the detectors will be across both lanes of each approach, and between the railroad tracks and warning gates (11).

The cameras are connected to an input/output management device which is stored in a traffic cabinet. This traffic cabinet is connected, typically by phone line, to the supervisor computer, which handles the citation processing. In certain instances, an environmentally hardened supervisor computer can be installed along with the I/O management device inside the traffic cabinet. The AUTOSCOPE detection system can additionally perform the task of traffic data collection. Such factors that can be recorded are volume, vehicle classification, flow rate, headway, and average vehicle speed (15). While the AUTOSCOPE system was initially designed for intersection control, it has since been adapted for use with highway-railroad grade crossings in the U.S.

SAIC - Traffic Violator Grade Crossing Monitor

The violation detection sub-system of the Traffic Violator system uses another method which is different from the two products previously mentioned. When the railroad's warning system is activated, mounted devices which send out infrared beams are alerted. These beams are targeted across the violation area. When the beams detect a vehicle, the high resolution video system is activated (12).

The remote video system captures the image of the vehicle, time stamps it, and compresses and transmits the digitized form over basic phone lines to the central monitoring location (16). SAIC supplies housing and zoom lens for the high-resolution cameras, as well as a steel pole with brackets and mounts (1).

The Traffic Violator system uses two different modes in its capturing of digitally-recorded images. The first mode takes a wide-angle image of the crossing and a close-up image of the license plate. The second mode takes a time-lapse wide angle view of the crossing (1). This mode is designed for crossings that have a history of multiple violations occurring at a time, since multiple license plates can be identified on the high resolution images. Another feature, which is designed to enhance the effectiveness of the citation, is the inclusion of how close the train was to the crossing, or the number of seconds until impact (16). This demonstrates the true speed of the train, which drivers tend to underestimate (8).

The computer terminal is equipped with a customizable screen (16). The system requires AC power, and additional lighting might be needed (1). Since the video systems are accessed over basic telephone lines, railroad officials can use the system to remotely view the condition of the grade crossing equipment. Also, the presence of the video cameras is designed to deter vandals (17).

USPT - TRAXGUARD Automated Railroad Grade Crossing Enforcement System

The TRAXGUARD system has been used extensively throughout the world. TRAXGUARD was first used in the Netherlands, and when the number of violations decreased dramatically, its use was expanded to other locations in Europe (18).

Violation detection is accomplished by inductive loops in the pavement, which are placed in similar locations to the previous loops and sensors that have been discussed. Since the loops can not measure speed, the second photo is automatically taken after a predetermined amount of time. This amount of time has been usually set as two seconds after the gate arms have began their descent. Both photos are superimposed with violation data (1).

Since TRAXGUARD has been around since the late 1980's, it uses an older method of recording violations. It uses high-speed 35-mm cameras, which come equipped with zoom lenses. A flash system is also included, if it is deemed necessary. These cameras are housed in an environmental, bullet-proof cabinet on pre-wired, steel observation poles. (12, 19). Field tests in Europe have typically employed the use of five empty

cabinets for every cabinet with a TRAXGUARD camera. The TRAXGUARD cabinet can be randomly rotated among the involved crossings. This method is meant to cause uncertainty among potential crossing violators as to which crossing is actually being monitored (18).

Unlike the other three products, the TRAXGUARD data is stored in camera itself. Film retrieval is typically done daily during the work week. This system does not require telephone lines to be nearby. The inclusion of early technology in the system translates to a low cost. The TRAXGUARD system's cost has led to it being installed at numerous crossings around the world.

Table 3 summarizes the features of the four major products.

Table 3. Features of Four AE Products

Product	Violation Detection	Violation Recording	Access of Data
SafeTrax RC-200 (<u>13</u>)	Piezoelectric/ Inductive Loops	Digital	Remote
AUTOSCOPE (<u>15</u>)	Video Imaging	Video Imaging	Remote
Traffic Violator (<u>16</u>)	Infrared Beam	Digital	Remote
TRAXGUARD (<u>12</u> , <u>19</u>)	Inductive Loops	35-mm	Manual

Other Products

With the increase in use of AE in the U.S. over the last decade, other companies are developing AE devices for use at highway-railroad grade crossings. Products such as the Harmon Highway Crossing Analyzer are new and have not been extensively tested (17). Other companies started their products in the field of traffic light enforcement, and are adjusting them to be usable in railroad crossing applications. One of the U.S. manufacturers that is attempting this action is Kodak. Their Digital Traffic Camera has yet to be used in a highway-railroad grade crossing project, but it has experience in the areas of speed, toll road, and border crossing enforcement, as well as traffic light enforcement. The camera uses special circuitry to handle difficult lighting conditions and a 100 microsecond shuttering designed to eliminate blurry images caused by motion (20). European companies include Gatsometer B.V. in the Netherlands, Zellweger Uster AG in Switzerland, and Proof Digitalsystemer A/S in Denmark (14).

HIGHWAY-RAILROAD GRADE CROSSING AE PROGRAMS IN U.S.

This section contains a review of the applications of AE of highway-railroad grade crossings in the U.S. The areas which have installed AE for the field are Los Angeles, California; Jonesboro, Arkansas; and Ames, Iowa. Covered in this review are the reasons for the initiation of their respective AE program, technology that was used, public information campaigns, enforcement and citation procedures, and the overall effectiveness of the AE program. This information was gathered from an extensive literature review.

In addition, the demonstration projects in the U.S. are discussed. These were initiated by transportation agencies in North Carolina and Texas, and the city of Miami, Oklahoma. The factors that were considered in the tests and the results are also reviewed.

Los Angeles, California

In a survey that was conducted by the Los Angeles County Metropolitan Transportation Authority (MTA) on residents along the 22-mile Metro Blue Line (MBL), which connects downtown Los Angeles to Long Beach, many problems were identified (21). The identification of these problems was the first step to a major enforcement program of the area's crossings. The line contains more than 100 highway-railroad grade crossings. For twelve miles, the light rail line runs through heavily-populated downtown city streets and adjacent to Southern Pacific freight lines. Between July 1990 and January 1995 more than 250 train-vehicle and train-pedestrian accidents occurred, causing 27 fatalities (5). It was discovered that 76 percent of the residents who used the crossings at least once a week also stated that drivers that tried to beat trains by driving around the gates were a serious problem.

Other responses which indicated the causes of the collisions include that it was not known that Blue Line trains arrive at the crossing within 20 seconds of the warning lights flashing (80 percent of responding residents), Southern Pacific's freight trains were too slow (70 percent), and that it was not widely understood that multiple trains could go through the intersection at the same time (21). This combination of slow and fast-moving trains was a major contributing factor in these accidents. Reports suggested that motorists, seeing a slow oncoming Southern Pacific train, attempted to cross the gates and would be struck by an obscured MBL train (12).

Other factors, in regard to geometry, which contributed to the high number of accidents were reported as (22):

- Streets running parallel to the tracks made it easier for motorists making left turns from these streets to drive around lowered crossing gates;
- The width of most of the crossings were increased from the presence of three or four tracks, which made it easier for motorists to drive around the lowered gates;
- Motorists' confusion over traffic signals and signing at the intersection; and
- Unusual crossing configurations.

In response to these problems, the MTA's Board of Directors initiated the Metro Blue Line Grade Crossing Safety Program in March 1993. The program was formalized to implement new plans to discourage violations at highway-railroad grade crossings. The previous year, tests had been conducted concerning enforcement with traffic stops and AE.

For a three-month period in the summer of 1992, the MTA used a system of increased police presence and enforcement. While the program was very successful, with 3503 citations being written for violations where drivers had traveled around the gate arms, the costs of the demonstration was too large. The MTA needed an easier and cheaper method of enforcement (21).

Beginning in 1992, the MTA conducted four demonstration projects involving the installation of photo enforcement systems at four highway-railroad grade crossings along the MBL, which had proved to be an effective tool at deterring speed and traffic light violations in the U.S. and Europe. Two of these projects were at crossings with gates, and two were at crossings without gates. For the scope of this report, only the results of the gated crossings will be discussed (21).

Chosen Technology

After seven vendors responded to the MTA's advertisement, four were chosen based on their experience with AE for traffic lights and crossings. Three accepted the invitation to participate. U.S. Public Technologies was chosen for the two sites that featured gated crossings - Compton Boulevard and Alondra Boulevard.

Both had three tracks passing through the crossing and a parallel street on both sides. Cameras on the southeast corner of the crossing monitored traffic in the eastbound traffic lanes (21).

The MTA absorbed all the funding for the projects related to the equipment acquisition and installation, which was \$50,000 for a camera and \$10,000 for the installation onto a pole at one intersection. Signs alerting motorists to the presence of photo enforcement were also installed. The U.S. Department of Transportation funded an evaluation on the effectiveness of the project (1).

Citations

The dollar amounts of the citations were in accordance with the provisions of the Rail Transit Safety Enforcement Act. This stated that the fine for not stopping at a gated crossing with signals flashing or driving around closed gates was \$104. The court was further authorized to levy an additional \$100 for a first-time violation and an additional \$200 for any subsequent offense (23). Figure 1 is a violation photo taken by the system that was used to issue a citation (21).

Effectiveness

In regard to Compton Boulevard, the first informational press conference was held on January 19, 1993. Between this date and March 19, 1993, warning letters were sent to motorists that were detected by the system as committing violations. From March 19, 1993 until July 19, 1993, when the study was completed, 548 violations were recorded and 232 citations were issued. Reasons for the large number of non-cited violators were the effect of the sun's glare in the photos, cars without frontal license plates, and license plate numbers without a match in the Department of Motor Vehicles' database (12).

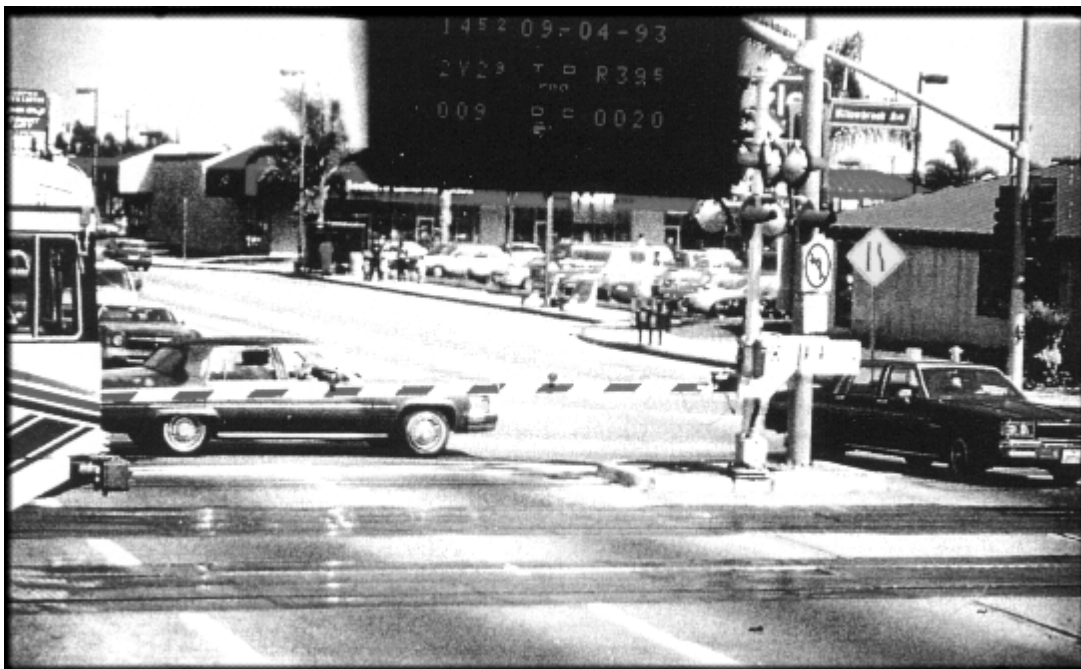


Figure 1. Photo From AE Program in Los Angeles (21)

The project resulted in a 92 percent drop in violations, with 0.15 violations occurring per hour for the last two months of the study. When the system was restarted for the last 21 days of September, the violation rate had fallen to 0.07 per hour (21).

The three-month Alondra Boulevard study was completed on September 9, 1993. The equipment had been in place for six months before the study began. Crossing violation rates fell from 0.5 per hour in December 1992 to 0.16 per hour when the project was completed. When the study had first begun, the rate had fallen to 0.28 per hour. The MTA attributed this decline to the visibility of the signs and cameras to the driving public. During the study period, 254 violations occurred at the crossing, with 142 resulting in citations (12).

Due to the success of the Los Angeles demonstration program, AE has been expanded to seventeen crossings along the MBL. At each crossing, poles, cabinets, and detector loops were installed. A total of ten camera systems were purchased by the MLA, and these cameras were rotated from one crossing to another at different intervals. In the two years since this program was started, 5,000 citations have been issued, with a 95 percent rate of conviction. Train/vehicle collisions at gated crossings have been reduced by over 70 percent (24).

Public Awareness

In addition to the major press conference that was held on January 19, 1993, photo enforcement signs, public service announcements, and posters were distributed before the study began.

Jonesboro, Arkansas

In 1991, officials of the city of Jonesboro, Arkansas and Burlington Northern and Santa Fe Railroad combined efforts to install and test the first AE highway-railroad grade crossing system in the U.S. The main reason Arkansas was selected was because the state treated highway-railroad grade crossing violations similarly to parking violations, where a citation is mailed to the owner of the vehicle (1). A crossing on East Highland Drive was selected. The crossing had experienced three fatal collisions during 1990, and five other collisions in the previous five years. In addition, the gates at the crossing had to be repaired frequently. Prior to the installation of the AE system, the average number of times the gates had to be repaired had risen to three per week (5).

Chosen Technology

The company SAIC, which now produces the Traffic Violator system, was chosen to provide the equipment. The Video Masters/Traffic Monitor system was purchased for \$50,000 from SAIC. Video cameras were mounted on pole brackets and encased in protective housings. Information that was collected was sent to the police department via a standard telephone line (1,12). The infrared beam detected vehicles, and the computer at the Jonesboro police station had storage capacity for data on 500 violators (25).

Citations

Violators received a cover letter which outlined the Arkansas statute that authorizes citations to be issued to registered vehicle owners, the citation, and two photographs showing the offense. If convicted, the violators were fined \$100 plus the costs of the court (12).

Effectiveness

Twelve months after the system had been in place, officials reported that the gates had been knocked down six times and ten citations had been issued (25). The violation rate was estimated to be two per month during the time period the system was functioning (1).

City officials determined that lightning had apparently struck the system eighteen months after it was installed. The system had been disabled by the electric surge. After the railroad repaired the system, another malfunction occurred in 1995 which caused the system to transmit blank images. The railroad and city officials agreed that the system should be repaired by the railroads (1). The author contacted the officials involved and their comments on the status of the system are included in the next section.

Public Awareness

Extensive local newspaper coverage was done during and after the plan's installation. Television companies did report on the ribbon-cutting ceremonies. These activities were designed to heighten public awareness. Unlike other installations, there were no warning signs to inform the motorists of the presence of the AE system.

Ames, Iowa

Ames officials met with members of the Iowa Department of Transportation and the Federal Highway Administration after 11 accidents occurred in 17 years at the highway-railroad grade crossing at Duff Avenue. This crossing was close in proximity to the intersection of Duff and Main Street, and thus experienced a heavy volume of traffic (20,000 vehicles per day). The train volume was 50 to 60 trains per day over two tracks, with speeds of 30 to 40 mph. Three accidents over a five-year period were directly attributed to violators driving around lowered gates. During this period of time, the AE projects in Los Angeles and Jonesboro were reviewed (1).

Chosen Technology

The city examined the abilities of the USPT, which was in place in Los Angeles, and the SAIC system, which was in Jonesboro. Officials used the characteristic of remote access to choose the SAIC system, and SAIC performed most of the installation. The project cost an estimated \$50,000, and the City of Ames assisted in installing cabinets and erected utility poles to provide power to the AE system (5, 26). The SAIC Traffic Violator system provided high-resolution images of the drivers, which was required by state law, and used infrared beams for violation detection (5).

After the system began operation on May 1996, city officials, who had conducted demonstration tests during the previous winter, determined the detection systems were not going to be effective. The cold weather that Iowa experiences during these months convinced them to plan an upgrade. The infrared sensors were not operating correctly, and the city officials decided on loop detectors. During July 1997, the system was temporarily removed to perform the upgrade, which was completed in September 1998 (6). Figure 2 demonstrates the Duff Avenue crossing layout.

Citations

A certain traffic law negated some of the efficiency and cost-effectiveness of the AE program. An Iowa state law requires that citations be hand-delivered to the violator's home, instead of mailing. In addition to this inconvenience and the fact that the gate arms had a tendency to malfunction, city officials decided that citations would be issued only for drivers who travel under and around the gate arms after the first few seconds of them being lowered. If the gates have been down for an excessive period of time, drivers could travel around the gates. Also, violations were only recorded during certain time intervals (1).

Effectiveness

Due to the fact that the photographs lacked a high level of resolution, in many cases the driver was unidentifiable. Also, it was difficult to identify nighttime violators due to the retroreflective material of the

license plates. This was the case for the 92 violations which were committed between May 1996 and June 1997. Instead of issuing citations, the city delivered warning letters to registered owners of violating vehicles during the day. Since June 1997, 37 violations were recorded and four citations were issued, which includes the time the system was offline (1).

Public Awareness

A public information campaign began toward the end of 1995. The campaign featured articles in local newspapers and advertisements on television. Warning signs were also installed in locations in advance of the crossing (12).

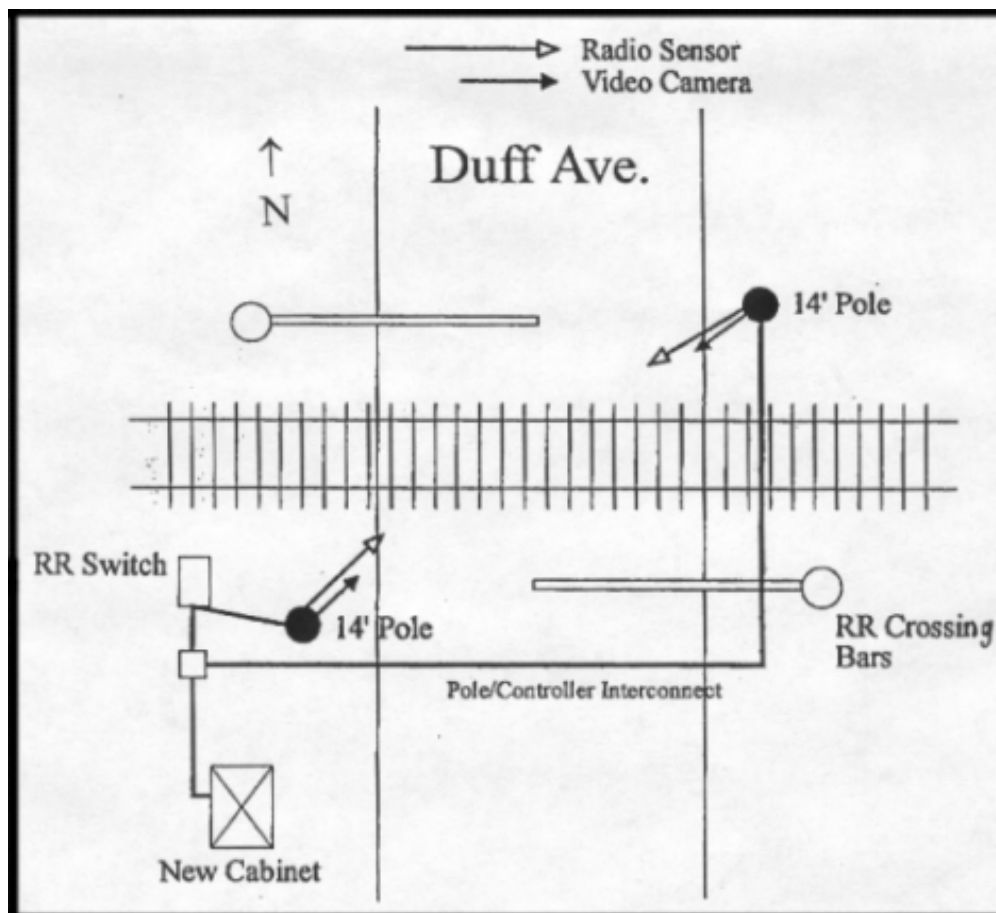


Figure 2. Layout of AE system at Duff Avenue (26)

Table 4 summarizes the characteristics of the three AE programs in the U.S.

Table 4. AE Programs in U.S. (1, 12)

Location	No. of Crossings	Date Program Began	Subsystem			Citations/Warnings
			Detector	Recorder	Access	
Los Angeles	17	1992	Loops	35-mm	Manual	5000+ Cit.
Jonesboro	1	1991	Infrared	Digital	Remote	10 Cit.
Ames	1	1996	Loops	Digital	Remote	4 Cit. / 92 Warn.

Norfolk Southern Corporation, NC

In 1992, the Washington D.C.-Raleigh-Charlotte rail corridor was selected as one of the five nationally-assigned high-speed rail corridors. With the increased speed of the trains along the line, the likelihood of tragic collisions also increased (16). Therefore, the North Carolina Department of Transportation (NCDOT) received federal funds to develop highway-railroad grade crossing safety improvements for this corridor. The Norfolk Southern Corporation was chosen to demonstrate video monitoring at several crossings (1).

After a 20-week study was completed to acquire an average violation rate, the data was used to formulate improvements to the crossings. The Norfolk researchers looked at strategies that would reduce the number of drivers that intentionally ignore crossing gates. Possible solutions included building pavement-mounted median barriers and quad-gates, which covered all lanes in each direction of travel (27). The data was also used to start a couple of AE programs. A SAIC video camera system has been installed at the Henderson Road crossing in Salisbury NC to be used in conjunction with these other improvements. Violators had the choice of either paying a fine or participating in a university study on violators (1).

Texas Department of Transportation

In 1995, the Texas Department of Transportation (TxDOT) was authorized by the state legislature to conduct demonstration projects to install and operate AE systems at highway-railroad grade crossings. By August 1997, three crossings in Texas had been reviewed, with the product manufacturers being SAIC, USPT, and American Traffic Systems. At one of the sites, the vendors mailed the violators educational letters. At the other two sites, the information was provided to the local police department for further processing (1).

The researchers concluded that AE equipment could clearly be used at highway-railroad grade crossings. However, the researchers did at times have problems identifying the license plate of the violator. This was the cause of 40 to 50 percent of the captured images being deemed unusable. A majority of the unused images had been captured while the front or rear plate was still out of view. They determined that the equipment involved would need adjustments before it could be applied on a permanent basis (5).

An AE issue that was not addressed by the project researchers was the process of issuing citations and the efforts required to implement the AE program on a large scale (5).

Miami, Oklahoma

This city modeled its plan after that of Jonesboro, Arkansas, and chose SAIC to provide the AE systems. The characteristics of the site include a low train volume of five trains per day and 14,000 vehicles per day. As of July 1997, the equipment has not been installed (1). The author was not able to contact the city for an update on the project.

INFORMATION ACQUIRED FROM AE PROGRAM OFFICIALS

The author attempted to contact officials that were involved in with the AE programs and demonstration projects in the U.S., and was successful for three of the six locations discussed in the previous section. The officials who were contacted were:

- Allen Kuhn - Burlington/Santa Fe Railroad;
- John Waldrip - Arkansas State Highway and Transportation Department;
- Rick Brown - Iowa Department of Transportation; and
- Paul Carlson - Texas Transportation Institute.

In addition to answering a few questions concerning the AE location they were familiar with, the officials also provided items such as crossing sketches, memos, and newspaper and magazine articles. Sample questions that were asked are included in the Appendix.

Jonesboro, Arkansas

Burlington/Santa Fe Railroad was one of the leading proponents for installing AE at the East Highland Drive crossing. Allen Kuhn, a Burlington public works engineer, negotiated the agreement with the City of Jonesboro. It was decided that the railroad company would pay for and install the system. Jonesboro provided the power source (28). Kuhn, the leading railroad official involved with the project, initially had no concerns that the AE system would hinder the normal operation of the railroad in any way. Kuhn stated that the AE system had never been intrusive, and believed that the railroad employees felt safer knowing the system was in place (29).

The present status of the AE system was also determined. John Waldrip, an employee of the Arkansas Transportation Department, stated that the system was never repaired after blank images began to be recorded in 1995. Disagreements arose as to how the system should be handled, and it has remained offline for the past four years (30). Kuhn noted that there had been ten violations of the crossing when the system was operational, and was in favor of it being brought back online. Kuhn also said that the violations had all occurred shortly after the AE system was first implemented (29). Other concerns have required the city officials' attention in the time since the system has gone offline.

Ames, Iowa

Rick Brown, an official of the City of Ames, provided insight to the installation at Duff Avenue. Union Pacific was the railroad that was involved in the AE project and was in favor of the installation of the system. Brown stated that Union Pacific did not have any major concerns or questions. A federal safety grant funded a majority of the project, and Union Pacific contributed 10 percent of the funding. Brown confirmed that four citations had been issued to drivers for violation of the Duff Crossing (26).

Cold weather was blamed for the malfunction of the infrared beams. This problem with the infrared beam system caused the officials to switch to inductive loops for violation detection. The lack of high resolution

on the images was the reason for only four citations being issued, a very low rate. Brown stated that this flaw of the system has been repaired and the AE program has been performing well (26).

Texas Department of Transportation

Paul Carlson, a research scientist for the Texas Transportation Institute, stated that there were several problems with the TxDOT project producing photos that were precise. In many photographs, the gate arms of the crossing were not visible. The presence of the arms was needed in order for the photo to be admissible in court. As was mentioned in the Technology section, any photo captured with AE must demonstrate that the warning system of the crossing was operating correctly. To correct this problem, the cameras were reprogrammed to begin recording the violations earlier after detection. It was also necessary to reposition several cameras (31).

More than 80 companies expressed interest in the demonstration project, and thirteen companies were represented at the pre-proposal conference. Carlson interpreted this as demonstrating the broad market for AE technology, and the bright future for AE applications in the U.S (31).

GENERAL GUIDELINES FOR INSTALLATION OF AE SYSTEM

This section contains an outline of the basic steps that an agency would take for an AE system to be set up at a highway-railroad grade crossing. The focus will be on the crossing's needs as related to geometry, climate, and advantages pertaining to certain equipment. It was assumed that public institutions involved in the project (city and state transportation departments, railroad companies, police departments, etc.) will have already aligned in favor of the program and have made basic preparations (1). Also, for this example, enabling legislation will already be in place (32).

Review of Applications in the U.S.

An in-depth study of AE programs that were either tried or that are still in place should be one of the first actions taken. In addition to the information that is provided in this report, copies of the community meeting discussions, AE proposals and blueprints, environmental impact statements, and estimations of costs should be obtained. With AE programs having existed in the United States for nearly a decade, there is a large amount of information that is available for each site.

The existing programs can be examined to find similarities between them and the crossing that is to be targeted for installation. This can save money in a variety of ways. The right type of technology can be chosen to best match the situation. A large amount of violations and an absence of available phone lines could make the choice of 35-mm cameras attractive. It is possible that the cost of manually retrieving the data could be offset by the savings of not having to install transmission wires for remote access. A large budget and workers that are well-trained could make the newer and more expensive digital cameras the ideal choice. If the accident history is extensive, and the agencies funding the project have enough resources, the expensive video imaging devices could be chosen.

Substantial money can also be saved if the problems that the previous programs experienced could be avoided. An agency planning to install AE at a highway-railroad grade crossing located in a particularly cold climate could benefit from the knowledge that infrared beams did not function well in Ames, Iowa. A costly system upgrade after a few years could be avoided (30). It is important to know what state laws exist that could threaten the normal operation of the AE program. The legality of AE citations might require both images of the vehicle's license plate and the face of the driver (12).

Establishment of Good Relations with Public

It is important that the citizens are aware that the proposed program is in the best interests of the community, and not a program whose goal is revenue generation. This can be accomplished by either setting the citation amount low enough so that the program is funded through the money received in citations, or by using the money generated for a high-profile transportation improvement project. Also, it is fundamental that the public is made aware of the situation as soon as possible. Sudden changes in the normal flow of driving can be irksome to motorists, so early print and TV ads are important. Advance signs warning of photo enforcement are important.

The railroad companies that were affected by the AE programs mentioned earlier in this report were highly involved in the installation process. Efforts by both the agency and the railroad company can be combined to increase public awareness.

Purchase of Equipment

Advertisements are distributed to manufacturers, preferably to as many as possible, to further the chance that the location's exact needs can be met. In drawing up the proposals and contracts, the agency involved must be very specific in what type of system it is looking for, and what special options and features are or are not important. Even if care has been done in reviewing previous applications so as to not repeat mistakes, large amounts of money can be wasted on technology that is either lacking or extraneous.

The agency must keep the nature of the community in mind. If the population tends to skew older, it could be possible to save money in buying material that is not bullet-proof, or contains an expensive anti-vandalism feature. If costs are intended to be cut by rotating cameras over several crossings, it is paramount to choose a system that can be easily dismantled and moved.

System Installation

Several factors must be considered once the needed technology has been purchased and the actual physical set-up is to begin.

The placements of the detection cameras need to grant an unobstructed view of the crossing. In other words, the cameras need to be high enough off the ground so that they can capture photographs over the traffic not involved in the violation. This is especially important if the crossing is in close proximity to a major intersection.

If suitable, mountable structures exist nearby, like traffic signal posts or telephone poles, it is important that the agency utilizes them. Money can be saved in taking advantage of previous work. The agency must be careful, however, in not creating a large distraction for the natural flow of traffic. If no such structures exist, it will be necessary to erect them. Steel posts have been the normal choice of past AE programs. A height of over 12 feet should make it possible to clear most obstructions (30). Several sample photographs must be taken to ensure that the camera location is correct if secondary images will be captured based on the vehicle's measured speed. Last but not least, the images must be able to demonstrate that the crossing gates are either in, going toward, or coming up from the lowered position.

For AE systems that require piezoelectric sensors or inductive loops to be placed in the pavement, more work is required. An effective work crew must be used up for its installation. Since the loops will usually be placed across both lanes of traffic, proper traffic control is necessary.

Lastly, all of the components need to be connected. To save power, the violation detection subsystem will likely be using the same train detection technology that the crossing's warning system uses. If the subsystem houses all of the data in a structure along the roadway, the job is slightly simplified. However, if it employs the latest technology for remote access, a little more work is needed in coordinating the violation recording subsystem and the citation processing subsystem.

Execution of Trial Runs

It is usually a good idea to begin the AE project as a warning mechanism, at least for the first couple of months after installation has been completed. The agency should use the citation processing computer to send out warning letters or educational literature to violators. This alerts the violators to a new but very important concern, and prepares them for when the time comes to start assessing actual fines.

Since only warnings are being handed out, this is also a good time to check the system for bugs and glitches in its operation. Since weather is one of the most important and variable factors, it would be advisable to have the trial run cover a length of time where the crossing will see different extremes in temperature and moisture.

Evaluation and Modification

After a certain length of time (usually about a year so that all expected variables will be experienced), it is important to measure and quantify what effect the AE system has had on the safety of the crossing in regards to its cost. In all of the present-day applications of AE that were studied, the numbers of violations and collisions went down soon after the system was installed. What is undesirable is if the program is requiring too large of a cost in relation to the light traffic volumes involved. It is also possible that other, more pressing transportation needs have surfaced since the AE program's inception. In such a case, a reduction in the amount of equipment (through the rotation plan) or an increase in the fine for citations might be in order.

APPLICATION OF AE PROGRAM TO CASE STUDY

The following section includes an analysis of the characteristics of a highway-railroad grade crossing in the College Station, TX area. Following this analysis is a list of the guidelines that were listed in the previous section to set up a hypothetical AE program. Choices were made based on what information was available, and a simple sketch was made of the layout.

The twin Texas cities of Bryan and College Station have a major rail line that runs north and south through their western half. This line runs in close proximity to Wellborn Road, a major arterial. Because of this location, the rail line experiences a large volume of crossing traffic each day. In addition, a major rail company runs several trains along the line each day. The highway-railroad grade crossings contain active warning systems, and the principal devices of each system are gate arms. While there is not an extensive history of collisions along this segment of track, the growing population of the surrounding area will continue to increase the volume these crossings experience, and thus the number of possible accidents.

The Holleman Avenue crossing in southwestern College Station was chosen for this application. Reasons for its selection include the presence of a major intersection nearby, Wellborn Road and Holleman Avenue, which is similar in physical layout to the crossings in Los Angeles and Ames, Iowa, and the train volume that it carries, which is about 25 trains a day (33). Its close proximity also granted the author convenience in its analysis. Holleman Avenue runs east-west, and the Wellborn intersection begins about 25 feet east of the rail line. The eastern leg of the avenue has four lanes, two in each direction, and after passing through the

intersection, the roadway is narrowed to two large lanes, one in each direction. Wellborn Road is a four lane roadway with left turn bays at the intersection. Figure 3 illustrates the crossing (34).



Figure 3. Photograph of Holleman Avenue Railroad Crossing (34)

As can be seen from the figure, there is a short segment of roadway between the intersection and the crossing. For the eastbound approach at the intersection, there is room for the storage of one vehicle. For additional vehicles on this lane, it is illegal to stop on the railroad tracks (9). These vehicles must remain on the opposite side of the railroad tracks until the traffic signal changes and they can proceed through the intersection. Vehicles becoming “trapped” on the railroad tracks when trains arrive should not be a problem since the intersection uses signal preemption. Signal preemption uses sensors on the railroad tracks to detect trains approaching the crossing. These sensors alert the signal control equipment and the signal timing plan is adjusted. Vehicles on the approach with the crossing will be granted a green light at the signal so that the vehicles will have enough time to clear the railroad tracks. This characteristic is important to consider in the implementation of an AE system. Whenever the violation detection subsystem is activated, it is expected that there will not be any vehicles that are traveling away from the crossing that would be detected as committing a violation (33).

The traffic signals at this intersection are operated under actuated signal timing plans. Actuated signals use sensors such as inductive loops in the pavement to detect vehicles and alter the signal phases (35). There is an inductive loop on the eastbound approach between the intersection and the crossing. It is approximately ten feet in length, which is about half the length of the eastbound approach.

The traffic signal mast arms have been installed in each of the four corners of the intersection. Also, there is a telephone line which runs north-south across the westbound approach.

Review of Applications in the U.S.

Since the Holleman crossing does not have a history of accidents, comparisons in this respect can not be made with existing AE programs. The factors that can be considered are the crossing's geometry and the area's climate.

After reviewing the AE programs in the U. S., the author determined that the crossing that resembled the Holleman crossing the closest was the East Highland Drive crossing in Jonesboro, Arkansas. Both have a single track and a similar volume of traffic, both train and vehicle. Los Angeles' crossings all feature multiple rail lines, and Ames' Duff Avenue carries a volume of 20,000 vehicles a day (5). Also, Texas and Arkansas experience similar climate due to their close proximity to one another. Therefore, equipment could be expected to perform similarly with respect to weather in both locations.

Establishment of Good Relations With Public

The Bryan-College Station local newspaper and the Texas A&M University newspaper reach thousands of readers a day, and news stories of the program would cause word of mouth to spread quickly. The local television station could be invited for a broadcasted interview of the primary officials involved. A graphical display of how the system would work would also be useful. Signs would be installed alerting the public of the presence of photo enforcement. Figure 4 is an example of a photo enforcement sign which is used by the Los Angeles MTA (5).



Figure 4. Photo Enforcement Warning Sign in Use in Los Angeles (5)

This sign is bilingual in nature due to the large Hispanic-speaking population of Los Angeles. It would be determined if a similar sign could be used at the Holleman crossing, based on whether the population makeup of College Station is similar to Los Angeles. The warning signs would be installed on each of the four approaches, in advance of the intersection. The sign on the eastbound approach would be placed about a hundred feet west of the crossing. The last action to garner good public relations would be to hold several

town meetings in the months leading up to the system installation to gauge the public's reaction and answer their questions.

Purchase of Equipment

Detectors that are placed into the pavement should be avoided, since the moderate amount of rain in the area could increase erosion of the roadway (14). The presence of inductive loops for the purpose of traffic signal actuation complicates the issue. One possible idea that came from a transportation professional was to use these inductive loops for violation detection. In this scenario, the violation detection subsystem would remain active due to the traffic signal controller requiring information pertaining to a vehicle presence. Instead of the violation detection subsystem becoming activated with the crossing's warning system, the violation recording subsystem would be the device that becomes operational (6). After the traffic signal controller is notified of a vehicle presence, this subsystem would capture the photos required.

If not for the size and placement of the inductive loop on the eastbound approach, this could be a plausible system. A site visit was made by the author to gather information on the geometry of the crossing and the intersection. It was discovered that the inductive loop does not extend far enough toward the crossing. It was determined that a vehicle committing a violation by driving between the gate arms could do so without traveling over the inductive loops. A violation could take place at the crossing without the vehicle being detected (36). This would defeat the purpose of installing an AE system at the crossing.

Another option for using this type of violation detection would be to install a second inductive loop between the crossing and the first inductive loop. This could, however, cause an undesirable side effect. Having two inductive loops placed into the pavement in close proximity could decrease the strength of the roadway. It might also hasten the rate of erosion, as was mentioned earlier.

Infrared beams would not cause any of these problems. They also should not be affected by the winter temperature in Texas as they were in Iowa (30). For that reason, and because video imaging is too expensive for a roadway that does not have an extremely large volume of train and vehicle traffic, the author chose infrared beams for the violation detection subsystem and digital cameras for the violation recording subsystem. A similar system has performed well in Ames, Iowa, and eliminates the need for visitation of the site. Also, there is a telephone line that runs north-south across the eastern leg of Holleman which could be used for sending the images. Two cameras would be purchased, and the equipment could be expected to be similar to the \$55,000 that Ames, Iowa spent on their initial system. The portion of the cost could also be paid by the involved railroad company, which was the case with the Jonesboro AE system.

Both the violation detection subsystem and the violation recording subsystem could be housed in the same cabinet. The cabinet would be made of bullet-proof metal.

System Installation

There is a traffic signal mast arm on each corner of the intersection. The mast arm on the southwestern corner could be used to mount one of the AE system cabinets. This would detect and record violators on the eastbound lane. Utilizing structures already in-place and not erecting a new mountable structure would save money. The cabinet would have to be placed as far off the ground as possible, which would be near the mast arm's joint. This height is needed so that vehicles traveling through the intersection would not be detected by the infrared beams.

The second camera would monitor violators in the westbound lane and could be placed on the northern side of the Holleman leg that is located west of the crossing. This would make the erection of a steel post necessary. The city of Ames, Iowa uses posts that are 14 feet in height, and a similar post could be purchased. The height is designed to grant the camera clearance. Care would have to be taken in the

placement of the post. It would be necessary to consult city's regulations in regards to sign placement and right-of-way.

Finally, the wires that transmit the information could be ran across the length of the traffic signal arm and be attached to the telephone wires on the poles across the intersection. These wires would eventually lead to the College Station Police Department. Figure 5 demonstrates the set-up.

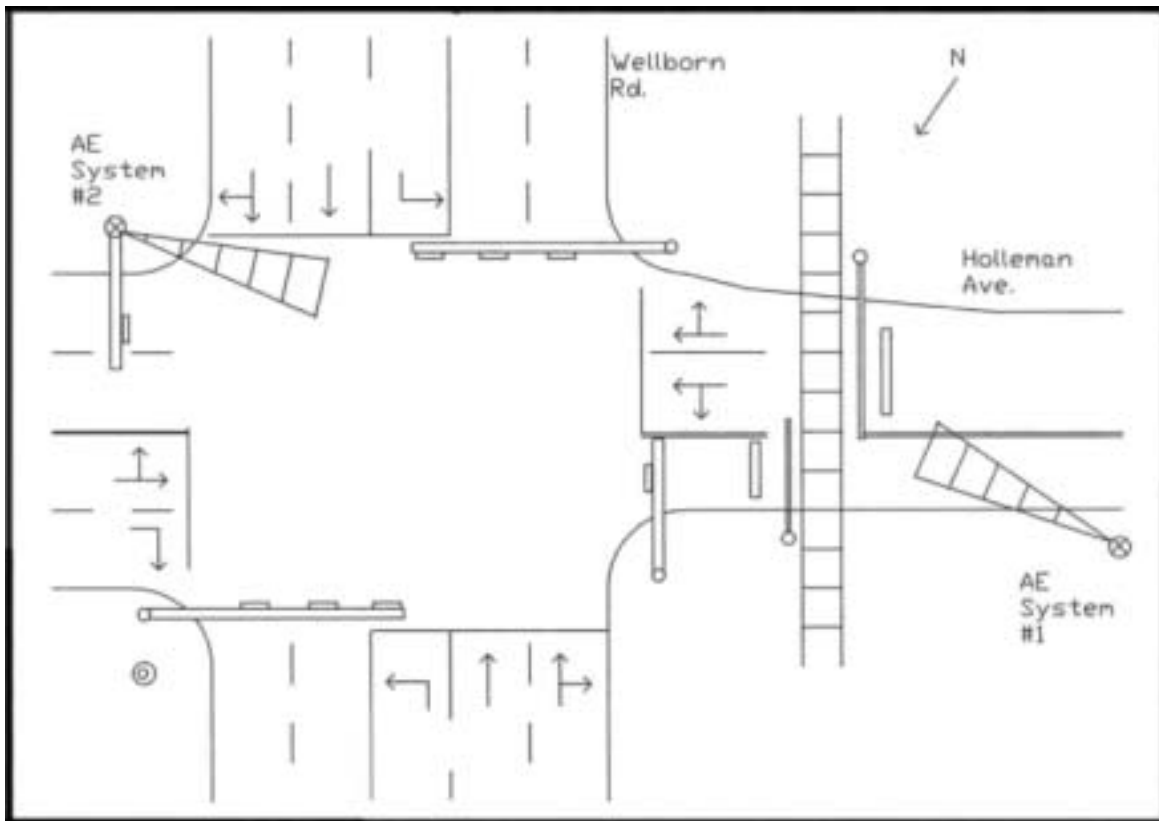


Figure 5. AE Installation for Holleman Avenue

Execution of Trial Runs

A three-month period would be used for the “warning-phase” of the program. During this time, violators of the highway-railroad grade crossing would be mailed warnings. The police department could also include educational literature in the form of brochures which illustrate the dangers of crossing violations. The period would also allow the system's engineers to identify and solve any technical problems in the system. The city could also answer any new questions from the public. In order for the weather extremes of the area to be experienced, the trial period would run from either February until April or September until November.

After the three-month trial period, citations would be issued to violators of the crossing.

Evaluation and Modification

After a one-year period in which citations were issued to violators, the costs and benefits of the program would be considered. The change in safety of the crossing would be determined by comparing violation and

accident rates of the crossing before and after the AE system was installed. If the safety of the crossing has not increased, the city should consider discontinuing the operation. It is the opinion of the author that the system would be deemed unnecessary. The light volumes of traffic and the lack of an accident history at the crossing would render AE an extraneous choice. Table 5 summarizes the recommendations for the AE system at the Holleman crossing.

Table 5. Summary of Subsystems Chosen for Holleman Crossing

Subsystem	Subsystem Type
Violation Detection	Infrared Beams
Violation Recording	Digital Cameras
Citation Processing	Remote Access Via Telephone Wire

CONCLUSIONS

In conclusion, for the Holleman case study, the author reviewed the AE systems that were in place in the U.S. In particular, the Jonesboro and Ames systems were examined due to their similarities to the crossing and problems they experienced. It was determined that for violation detection, violation recording, and citation processing, the agencies involved should select infrared beams, digital cameras, and remote access, respectively. It would also be necessary to purchase and erect a 14-foot steel poll. The author speculated that the system would eventually prove to not be cost effective. The question of cost effectiveness is the main issue facing automated enforcement proponents in the future. Practically all tests and demonstration projects have shown that AE is effective in reducing traffic violations. In today's world, however, transportation officials must make difficult choices in the allocation of funds.

Keeping the public involved in the process is essential to the support and success of an AE system. The public must be convinced that public servants are making an effective use of an already limited supply of time and resources.

In comparison with other transportation technologies and advances, AE is still relatively new. Continued research and study is needed to not only validate the present uses, but to develop new and innovative applications for AE in the future.

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APPENDIX: SAMPLE INTERVIEW QUESTIONS

Transportation Department contacts

- How long, and where, have you been involved with the use of automated enforcement in general, and for railroad crossings in particular?
- What was the process that was carried out in selecting AE as a potential solution?
- What were some of the problems that arose in implementing the AE system?
- In addition to history of accidents, what other factors were considered when selecting crossings for demonstration or implementation of the AE system?
- What issues did the railroad professionals raise in you discussions with them?
- How has the public accepted the use of enforcement through the use of digital cameras?
- What changes (if any) would you like to see be done in your AE program?

Railroad contacts

- What were some of the concerns you had when the issue of AE came up?
- In what way (if any) has the use of AE affected the normal operation of the railroad system?

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