Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

Urban and Rural AHS Comparison

U.S. Department of Transportation
Federal Highway Administration

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FOREWORD

This report was a product of the Federal Highway Administration's Automated Highway System (AHS) Precursor Systems Analyses (PSA) studies. The AHS Program is part of the larger Department of Transportation (DOT) Intelligent Transportation Systems (ITS) Program and is amulti-year,multi-phase effort to develop the next major upgrade of our nation's vehicle-highway system.

The PSA studies were part of an initial Analysis Phase of the AHS Program and were initiated to identify the high level issues and risks associated with automated highway systems. Fifteen interdisciplinary contractor teams were selected to conduct these studies. The studies were structured around the following 16 activity areas:

> (A) Urban and Rural AHS Comparison, (B) Automated Check-In, (C) Automated Check-Out, (D) Lateral and Longitudinal Control Analysis, (E) Malfunction Management and Analysis, (F) Commercial and Transit AHS Analysis, (G) Comparable Systems Analysis, (H) AHS Roadway Deployment Analysis, (I) Impact of AHS on Surrounding Non-AHS Roadways, (J) AHS Entry/Exit Implementation, (K) AHS Roadway Operational Analysis, (L) Vehicle Operational Analysis, (M) Alternative Propulsion Systems Impact, (N) AHS Safety Issues, (O) Institutional and Societal Aspects, and (P) Preliminary Cost/Benefit Factors Analysis.

To provide diverse perspectives, each of these 16 activity areas was studied by at least three of the contractor teams. Also, two of the contractor teams studied all 16 activity areas to provide a synergistic approach to their analyses. The combination of the individual activity studies and additional study topics resulted in a total of 69 studies. Individual reports, such as this one, have been prepared for each of these studies. In addition, each of the eight contractor teams that studied more than one activity area produced a report that summarized all their findings.

Lyle Saxton
Director, Office of Safety and Traffic Operations Research
and Development

NOTICE

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16. Abstract

Implementation and daily operations of an AHS system are anticipated to be different in a rural or intercity environment as opposed to the urban environment. Variations of these environments will be manifested in the field, including fringe areas of heavily populated urban areas and small population centers along the intercity, otherwise rural, environment. Work in this activity area identified and analyzed the technical and operational differences of these environments and drew conclusions regarding the implementation of AHS when considering the three systems concepts. Due to the broad scope of this activity area, it sets the stage for many of the activity areas in the overall project. Thus, this work is considered to have high priority.

The implementation of AHS presents the opportunity to positively affect the single most important transportation issue identified in the course of the study – traffic safety. The effect of even a partially automated system, with collision avoidance and lane following features, would be to reduce urban and rural freeway accidents by a minimum of 30 and 25 percent, respectively. Accident reductions of this magnitude would eliminate approximately 71,000 accidents per year and $700 million in accident costs.

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EXECUTIVE SUMMARY

Objective and Scope

At the outset of this program it was anticipated that implementation and daily operations of an AHS system would be significantly different depending on the generic type of environmental setting—i.e., rural or urban. The objectives of this activity area, therefore, were to 1) look for the existence and nature of such differences and 2) identify the issues associated with these differences that would be likely to have a significant impact on the design, deployment, and/or operation of an AHS.

This activity area was one of eight activity areas analyzed by this program team. As such, the scope of this effort not only required achievement of the basic objectives outlined above, but a major role in providing the urban and rural information cornerstone for the other seven activity areas. This secondary role included providing ongoing input and collaboration on the development of both 1) the team's set of representative system configurations (RSCs) and 2) the team's integrated contract overview report.

The scope of this work was broadened somewhat to explore a third freeway area type referred to as *fringe*—i.e., a freeway situation intermediate between the urban and rural environments. Much of the background information for this effort was obtained from the State of Minnesota, but the scope of this activity included a literature search and outreach work to show that the Minnesota situation was not atypical for other States likely to be candidates for AHS deployment.

Methodology

The identification of technical, operational, and safety issues was accomplished primarily through a comprehensive literature search and a series of expert workshops. The literature search included identification and review of a broad range of previous AHS, IVHS, and related topic research and findings. This work supported a preliminary identification and/or confirmation and detailed description of major technical features, for example, 1) geometric design characteristics such as interchange design, lane width, and median configuration and 2) vehicle characteristics such as braking and acceleration capabilities. Accident type and severity data were also obtained and analyzed for various roadway categories and roadway improvements. Considering improved safety as a primary driver for the implementation of AHSs, current accident statistics were examined carefully to assess their potential utility as an indicator of likely AHS benefits.

A summary of freeway design and operating characteristic information was developed not only to guide the ongoing work in this activity area, but to serve as a key point of reference for the team's other seven activity areas throughout the remainder of the program.

Several workshops were held at different locations across the country and were attended by a good range of transportation experts (e.g., representatives of FHWA, FTA, State transportation agencies, auto makers, and academia). These workshops helped to identify issues and promote a working dialogue of AHS within the industry. Results from the literature search and expert workshops were synthesized to develop a matrix of technical, operations, and safety issues by locale (e.g., urban, rural, and fringe). Included in this matrix were elements such as

- Geometric design.
- Vehicle characteristics.
- Trip characteristics.
- Traffic flow behavior.
- Accident statistics.

Once this matrix was in hand, it was used as a basis for reviewing the team's set of RSCs—with special emphasis placed on comparing and contrasting the technical, operation, and safety characteristics in urban, rural, and fringe environments.

Results

Highlights of the results for activity area A are summarized in the following several paragraphs. Additional findings and supporting material are presented in the main topical report for area A.

Geometric and Operational Differences

There are significant geometric and operational differences in the three freeway environments reviewed, as characterized below.

Geometry and Traffic Patterns

Freeway Environ-ment	No. of Lanes in Each Direction	Speed Limits (mph)	Typical Type of Median	Average Weekday Traffic (Vehicle per day)	Congestion Levels	Typical Interchange Spacing (miles)	Interchange Type(s)
Urban	≥2	55	Barrier	>80,000	Recurrent Daily	1/2 to 1	System direc-tional inter-changes Std and half diamonds
Fringe	≥2	55	Barrier or grass median	20,000 to 80,000	Intermediate	3/4 to 2	Partial and complete cloverleafs with collector and distrib-utor road connections Standard and folded dia-monds
Rural	2	65	Wide median	≤20,000	No recurrent daily conges-tion	3 to 5	Cloverleaf and std. diamonds

From an aerial perspective, the fringe freeways more closely resemble the rural freeways. However, from a traffic pattern standpoint the fringe freeways are more similar to urban systems in being highly loaded and frequently congested.

Accident Frequency and Type

Accident Patterns	Accident Rate (Accidents/Million Miles of Travel)	Most Common Accident Types (% of Total)
Urban	1.7	· Rear end collisions (51%) ·Single vehicle run-off the road (18%) ·Side Swipes (17%)
Fringe	0.7	· Rear end collisions (40%) ·Single vehicle run-off road (21%) ·Side Swipe (15%)
Rural	0.7	· Single vehicle run-off road (34%) ·Collisions with animals (25%) ·Rear end (13%) ·Side Swipe (7%)

From an accident pattern standpoint, the fringe environment freeways tend to track the urban patterns, while the rural freeway situation differs greatly from fringe and urban situations in both accident rate and type.

Potential Benefits

From a highway engineering standpoint, the primary potential benefits of AHS deployment are the anticipated reduction of accidents. Considering the primary modes of accidents enumerated above, the planned capability for AHS to provide *collision avoidance* and *road following* features could eliminate or greatly reduce the the majority of accidents, which cost billions of dollars on U.S. urban, rural, and fringe freeways. Improved congestion management in the urban and fringe environments might yield capacity increases of 25 percent or more and would, of course, be another key anticipated benefit.

Implications of the activity area A findings in addition to reinforcing the need for and potential benefits of the AHS benefits are as follows:

- The urban and fringe freeway environments offer similar concentrated needs for improvement where the investments in AHS technology can be amortized over a much larger number of vehicles. Of the two, the more open geometry of fringe freeways would better lend itself to incorporating any changes in ramps, barriers, etc., than the true urban freeway.

- Carefully selecting and developing the on-board and roadway-installed AHS subsystems might permit use of a significant portion of the safety features of an urban or fringe AHS in a semi-AHS or standard rural freeway and, therefore, greatly increase their acceptance.

Conclusions

Reviewing the team's specific set of RSCs in light of the generic findings of activity area A suggests the following considerations and conclusions.

- RSC #1 is characterized as having vehicles with “average intelligence” operating on a “smart highway.” Because this RSC and the pallet based RSC (RSC #3) are nominally the most infrastructure intensive AHS types—the associated large investment requirements suggest that consideration of these AHS types should probably be restricted to the urban and fringe applications. As noted above, the urban and fringe freeways have much higher traffic volumes over which to amortize the expenses. Furthermore, the urban and fringe freeways account for only a small fraction of the total freeway mileage. Based on State of Minnesota data, for example, the distribution of total interstate freeway mileage across the three types is as follows:

Freeway Type	Portion of Mileage
· Rural	76.6%
· Fringe	18.2%
· Urban	5.2%

A corollary is that RSC #4, which features a basically passive guideway (therefore, relatively small infrastructure investment), is probably a good type of AHS for initial consideration for rural applications.

- RSC #2 may be characterized as a platooning based concept—it features intelligent/autonomous vehicles operating on a “dumb”/passive highway. Because a primary motivation for considering platooning based systems is increased capacity, the initial applications for consideration would probably be the urban and fringe freeway situation where 1) the traffic volumes and congestion problems are the most stringent and 2) the ability to add additional lanes is very limited and/or expensive. This latter consideration, however, could cease to be a favorable factor for platoons if 1) the actual means of implementing a platoon based AHS calls for exclusive ramps, breakdown lanes, or additional barriers that require appreciable space to incorporate and/or 2) it would take too long to make enough AHS vehicles available to increase the roadway's capacity. Unfortunately, it is likely that most, if not all, fully developed platoon based AHSs (such as this the team's RSC #2 variations—2A, 2B, and 2C) will call for one or more of the space requiring features just mentioned—i.e., exclusive ramps, breakdown lanes, and/or additional barriers.

- Many potential safety, initial capacity, environmental impact reduction, and system control advantages can be seen for the use of a pallet based system. However, pallet based systems are likely (as RSC #3) to pose offsetting impacts regarding 1) the amount of land required for storing and maintaining the pallets, 2) lane space for “recirculating” empty pallets, 3) energy use for “recirculating” empty pallets and moving *both* a pallet and a vehicle from point A to point B, and 4) access/egress delays.

- The implementation of AHS presents the opportunity to positively affect the single most important transportation issue identified in the course of this study—traffic safety. The effect of even a partially automated system, with collision avoidance and lane following features, would be to reduce urban and rural freeway accidents by a minimum of 30 and 25 percent respectively. Accident reductions of this magnitude would eliminate approximately 1,300 accidents per year in Minnesota and 71,000 accidents per year nationally and save $13 million per year in accident costs in Minnesota and $700 million per year nationally.

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ACRONYMS/ABBREVIATIONS

AARP	American Association of Retired Persons
AASHTO	American Association of State Highway and Transportation Officials
ABS	Antilock Braking System
ADT	Average Daily Traffic
AE	Architectural Engineer
AHMCT	Advanced Highway Maintenance and Construction Technology Program
AHS	National Automated Highway System
AICC	Autonomous Intelligent Cruise Control
ANSI	American National Standards Institute
APTS	Automated Public Transportation System
ARPA	Advanced Research Project Agency
ARTS	Automated Rural Transportation System
ASTM	American Society for Testing Materials
ATIS	Automated Traffic Information System
ATMS	Advanced Traffic Management System
AVCS	Automatic Vehicle Control System
AVI	Automatic Vehicle Identification
AVLS	Automatic Vehicle Location System
BBS	Bulletin Board System
CASA	Computer and Automated System Association
CE	Civil Engineering
CI	Configuration Items
CVO	Commercial Vehicle Operation
DC	Direct Current
DCAA	Defense Contract Audit Agency
DOT	Department of Transportation
DVI	Driver Vehicle Interface
EPS	Electric Power Steering
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FMEA	Failure Modes Effects Analyses
FMVSS	Federal Motor Vehicle Safety Standard

FOT	Field Operational Test
FREE-SIM	Freeway Simulation
FTA	Federal Transit Authority
FY	Fiscal Year
GIS	Geographic Information System
GPS	Global Positioning System
HOV	High Occupancy Vehicle
HW	Hardware
IAVD	International Association of Vehicle Dynamics
IEEE	Institute of Electrical and Electronic Engineers
IR	Infrared
IR&D	Independent Research and Development
ISO	International Standards Organization
ISTEA	Intermodal Surface Transportation Efficiency Act
IVHS	Intelligent Vehicle Highway Systems
MOE	Measure of Effectiveness
MOP	Measure of Performance
MPR	Mean Personal Rating
MTBCF	Mean-Time Between Critical Failure
MTBF	Mean-Time Between Failures
MVMT	Million Vehicle Miles Traveled
NADS	National Advanced Driving Simulator
NAHTSA	National Automotive Highway Transportation Society of America
NDS	National Driving Simulator
NES	National Energy Strategy
NHTSA	National Highway Traffic Safety Administration
NSC	National Safety Council
OEM	Original Equipment Manufacturer
PC	Personal Computer
PBMS	Performance Based Measurement System
PSA	Precursor Systems Analysis
QFD	Quality Function Deployment
R&D	Research and Development
SAE	Society of Automotive Engineers
TMC	Traffic Management Center
TRB	Transportation Research Board
TRAF-NET	Traffic Network Simulation
UL	Underwriters Laboratories

USG	United States Government
V&V	Validation and Verification
VMT	Vehicle Miles Traveled

INTRODUCTION

Task A of the AHS precursor systems analysis (PSA) consists of two distinct sets of tasks: establishment of a system reference framework to be used for all activity areas and the actual urban/rural analysis. The system framework focuses on how the individual areas of analysis form a cohesive concept of AHS operation. The objective of the urban/rural AHS analysis is to identify the technical and operational characteristics of urban and rural environments by representative system configurations (RSCs). This includes issues, opportunities, and risks related to AHS design, deployment, and implementation.

The analysis consisted of the following subtasks:

- Conducting a literature search of all relevant publications to ensure that previous studies were considered and not duplicated.
- Sponsoring a review of workshops attended by transportation experts from State and Federal transportation agencies, auto makers, and academia to share information, identify issues, and promote a working dialogue within the industry.
- Researching, compiling, and analyzing available data relative to urban and rural design characteristics, vehicle characteristics, trip characteristics, traffic flow behavior, and accident statistics.

The result of the analysis is a comprehensive listing of the identified opportunities and risks associated with implementation of an AHS system in an urban and rural environment.

This study required a defined set of AHS characteristics that could provide a framework for system analysis. AHS development is in its infancy, and the characteristics of a preferred AHS infrastructure, vehicle, or command and control structure have yet to be determined. Lacking a preferred definition, a set of definitions was created from discussions and submittals from the professionals familiar with automation, roadway, societal, and institutional issues. The RSC definitions are intended to provide a common framework for analysis among tasks and include a variety of competing AHS characteristics. All RSCs were considered equal in the analysis, and none received preference or priority. It is understood that this analysis will be used as input by design teams responsible for developing AHS technology and applications.

REPRESENTATIVE SYSTEM CONFIGURATIONS

For the purpose of this document, the research team considered four primary RSCs. Detailed descriptions of these RSCs can be found in the AHS PSA overview report.

In general terms, the RSCs can be summarized as follows:

Table 1. Representative system configurations.

RSC	Traveling Unit	Headway Policy	Vehicle Intelligence	Guideway Intelligence
1. Average Vehicle Smart Highway	Individual Vehicle	Uniform	Average	Active
2. Smart Vehicle Average Highway	Individual Vehicle	Platoon	Autonomous	Passive
3. Smart Pallet Average Highway	Pallet	Uniform	Autonomous	Passive
4. Smart Vehicle Passive Highway	Individual Vehicle	Independent	Autonomous	Passive
Note: [1]RSC 2 consists of three lane configuration variations, resulting in a total of six specific RSCs.				

Each RSC used in this research requires a specific definition of the associated roadway configuration. Three of the four primary RSCs (i.e., 1, 3, 4) were assigned only one roadway configuration, and one of the RSCs (i.e., 2) was assigned three different roadway configurations. The result is a total of six variations of the four primary RSCs, described by their *mainline*, *AHS access*, and *separation characteristics*.

Mainline

None of the RSCs investigated in this research effort involved a roadway which is completely AHS for all lanes, with no provisions for non-AHS vehicles. However, three distinctly different mainline roadway configurations were associated with the target RSCs and considered:

1. Two lanes in each direction, with the left lane in each direction serving mixed AHS and non-AHS traffic.

2. Three lanes in each direction with the left lane in each direction serving only AHS traffic.
3. Two lanes in each direction serving non-AHS traffic and a reversible lane between the non-AHS lanes serving only AHS traffic.

AHS Access

Access to the lane in which AHS is provided can involve a variety of entry/exit designs, some of which require maneuvering through non-AHS traffic to get to the AHS lane. Others simply provide direct access to the AHS lane via an exclusive ramp system.

For the sake of this research, entry and exit facilities were addressed only at a high level to determine compatibility with roadway design strategies. The main interest in entry/exit for this effort is simply to acknowledge whether a ramp system is on the left or right side of a lane set, spacing between terminals, and whether the ramp is intended for mixed or exclusive AHS flows. Other research teams have conducted detailed studies of entry/exit facilities (Area J—Entry/Exit Analysis) and their deployment, and have documented those results in other reports.

The following AHS lane access components were considered germane to the RSCs in this research:

1. Mixed Ramps—AHS vehicle enters/exits the freeway facility by using the same ramp facilities as non-AHS vehicles. Special lanes may be provided for AHS vehicles on the ramps to facilitate check-in and check-out, but the AHS vehicle must maneuver through non-AHS lanes when traveling between the AHS lane and the ramp system.

2. Exclusive Ramps—All entry and exit points serving the AHS are provided by ramps intended exclusively for the use of AHS vehicles only and are physically located such that no maneuvers by AHS vehicles through non-AHS traffic are necessary to reach the AHS lane.

3. Transition Lane—Similar to the mixed ramp concept where AHS and non-AHS vehicles utilize the same ramps, but includes a transition lane located adjacent to the AHS lane. The transition lane is used for maneuvers into and out of the AHS lane. Traffic flow in the transition lane may be AHS only or mixed flow, and AHS vehicles must maneuver through non-AHS lanes and traffic to reach the AHS lane.

Lane Separation

The means by which separation of AHS and non-AHS traffic is accomplished is closely associated with how entry/exit may be accomplished. In terms of the RSCs considered for this research, the following two concepts were considered:

1. None—Separation of AHS and non-AHS traffic is accomplished by signing and striping only.

2. Barrier—Physical barrier used to separate AHS and non-AHS traffic streams along the length of the AHS lane.

Using these characteristics, the resulting six variations of the four primary RSCs are summarized as follows:

Table 2. Global RSC characteristics.

RSC	Mainline Roadway Configuration	AHS Lane Access			Lane Separation	
		Mixed	Exclusive Ramps	Transition Lanes	None	Barriers
1	3 Lanes each direction Exclusive AHS Lt. lane	X		X	X	
2A	3 Lanes each direction Exclusive AHS Lt. lane	X			X	
2B	3 Lanes each direction Exclusive AHS Lt. lane		X			X
2C	2 Non-AHS lanes each direction Reversible excl. AHS center lane		X			X
3	3 Lanes each direction Exclusive AHS Lt. lane		X			X
4	2 Lanes each direction Mixed traffic Lt. lane	X			X	

The graphics on the following sheets illustrate the general roadway configurations of the six variations of RSCs used in this research. The basic assumptions as to how each RSC would operate in summarized in table 3. Detailed descriptions of characteristics beyond the roadway deployment characteristics may be found in the AHS precursor systems analyses overview report.

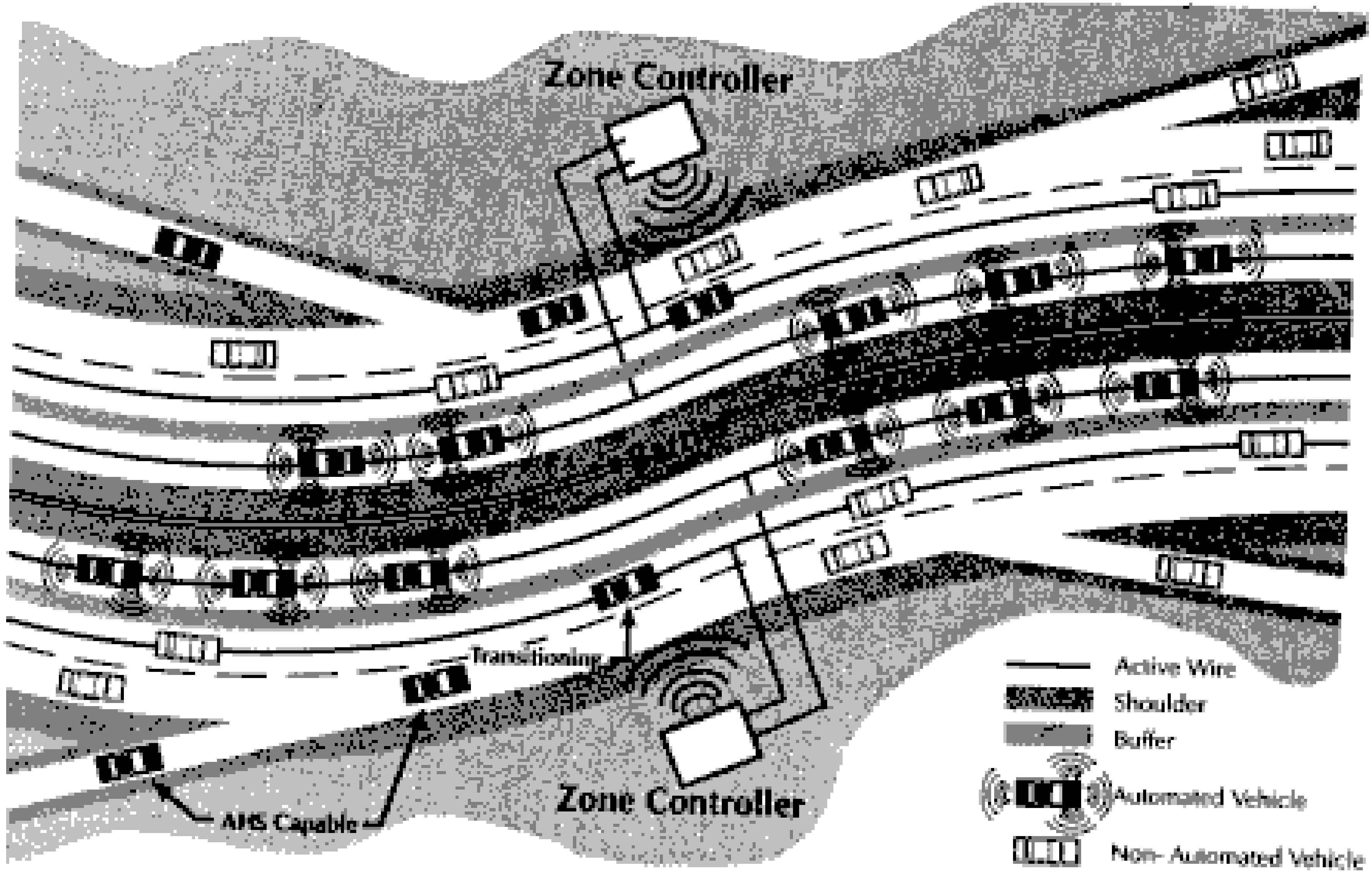


Figure 1. RSC 1.

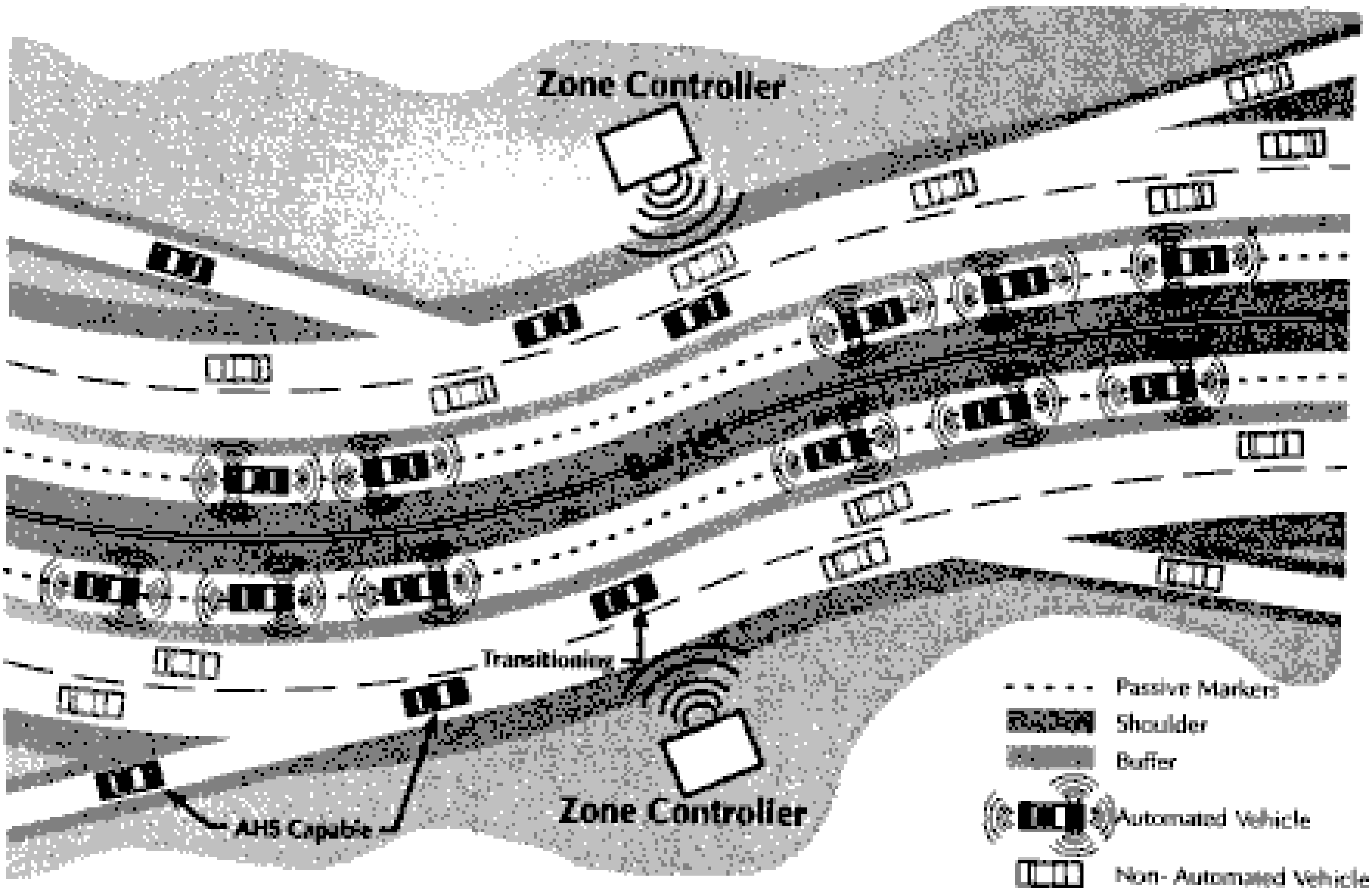


Figure 2. RSC 2A.

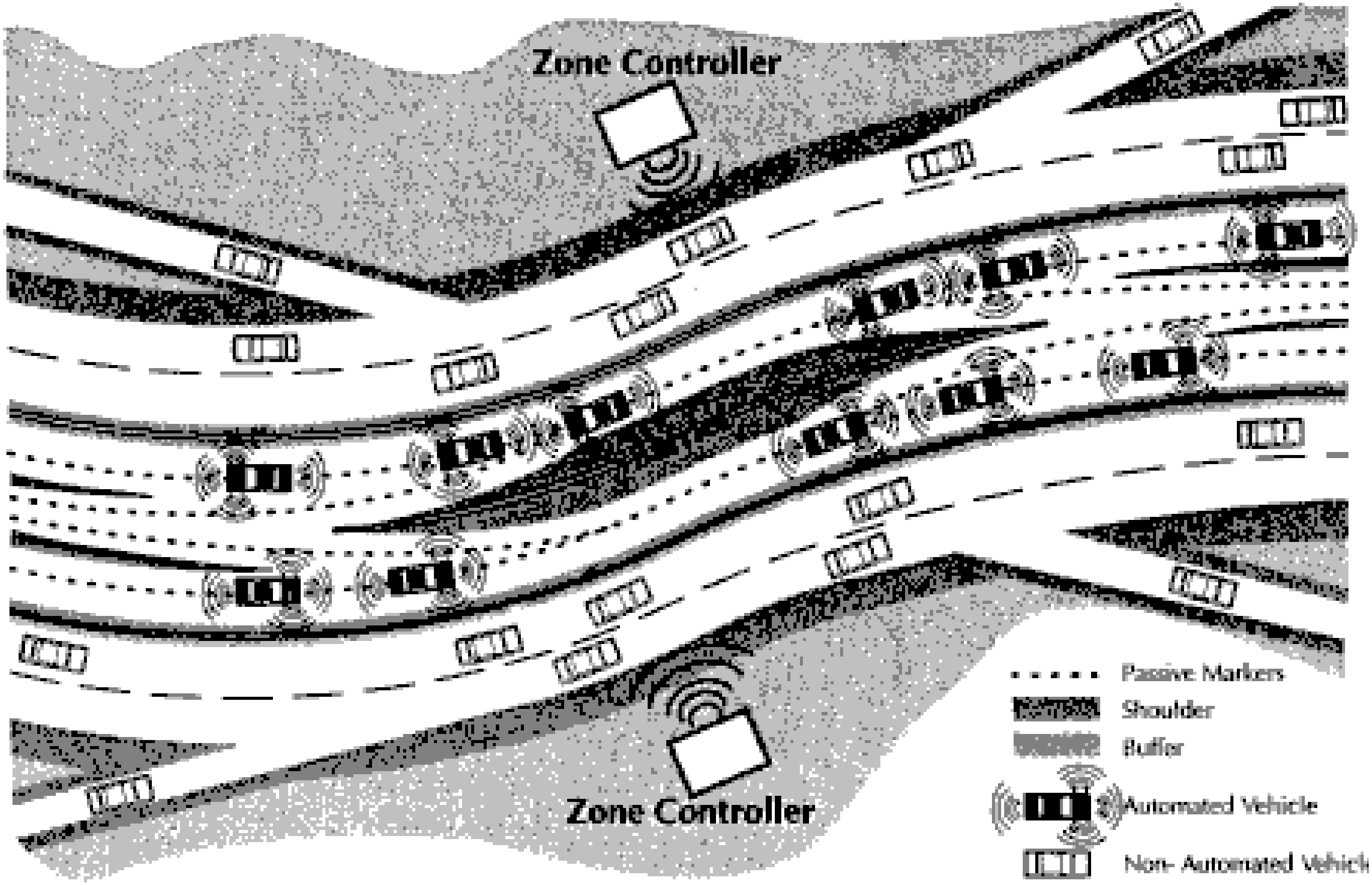


Figure 3. RSC 2B.

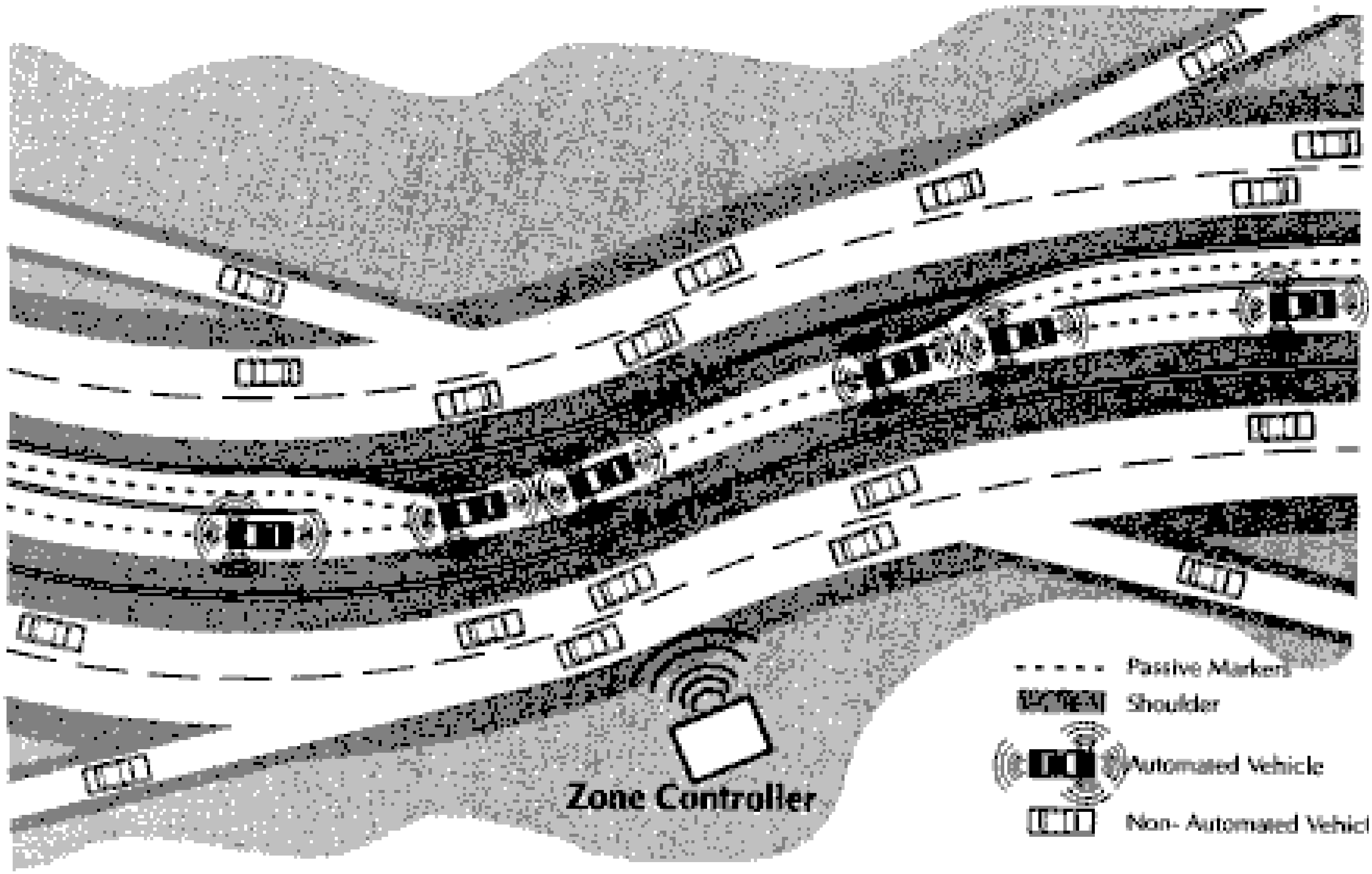


Figure 4 RSC 2C

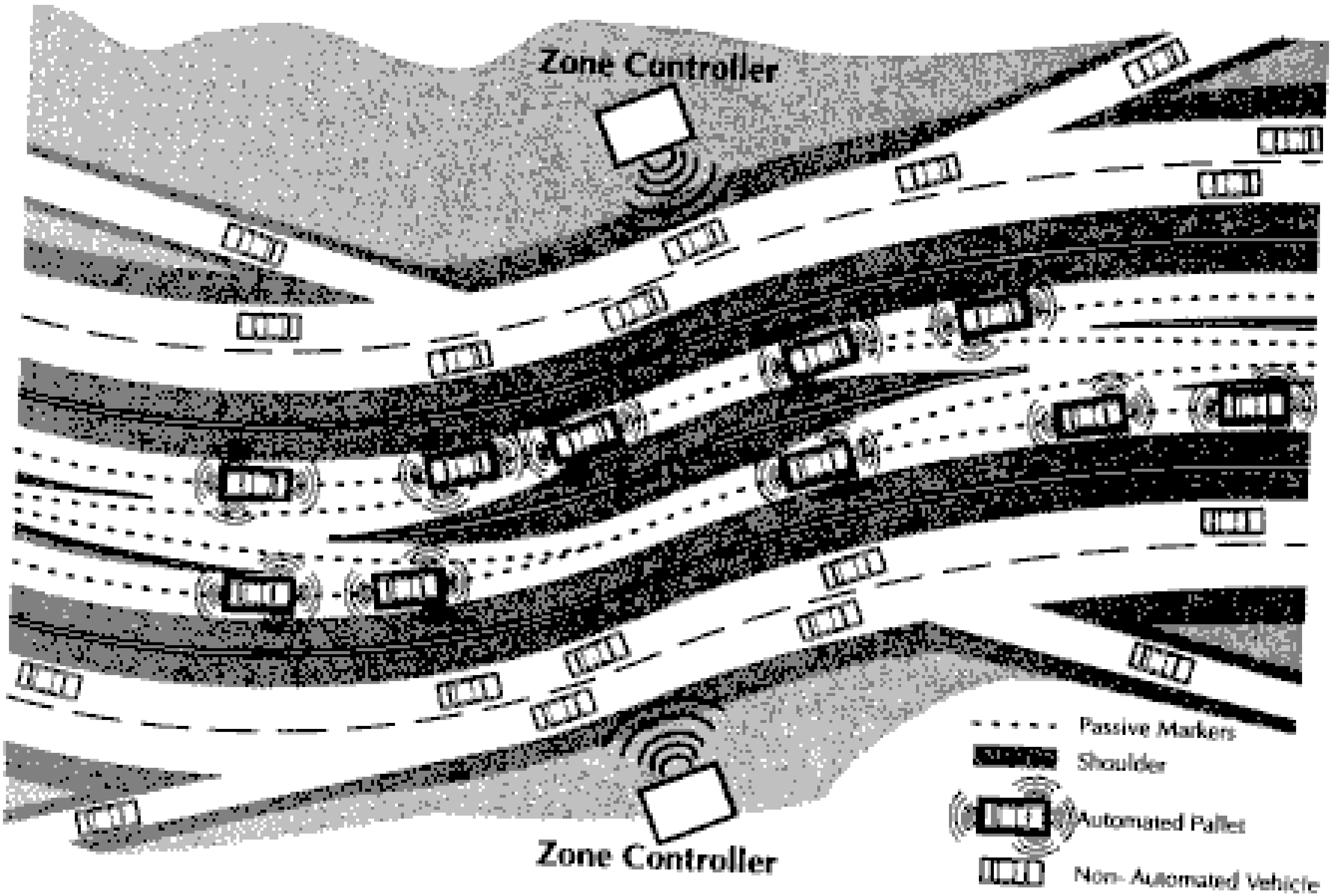


Figure 5. RSC 3.

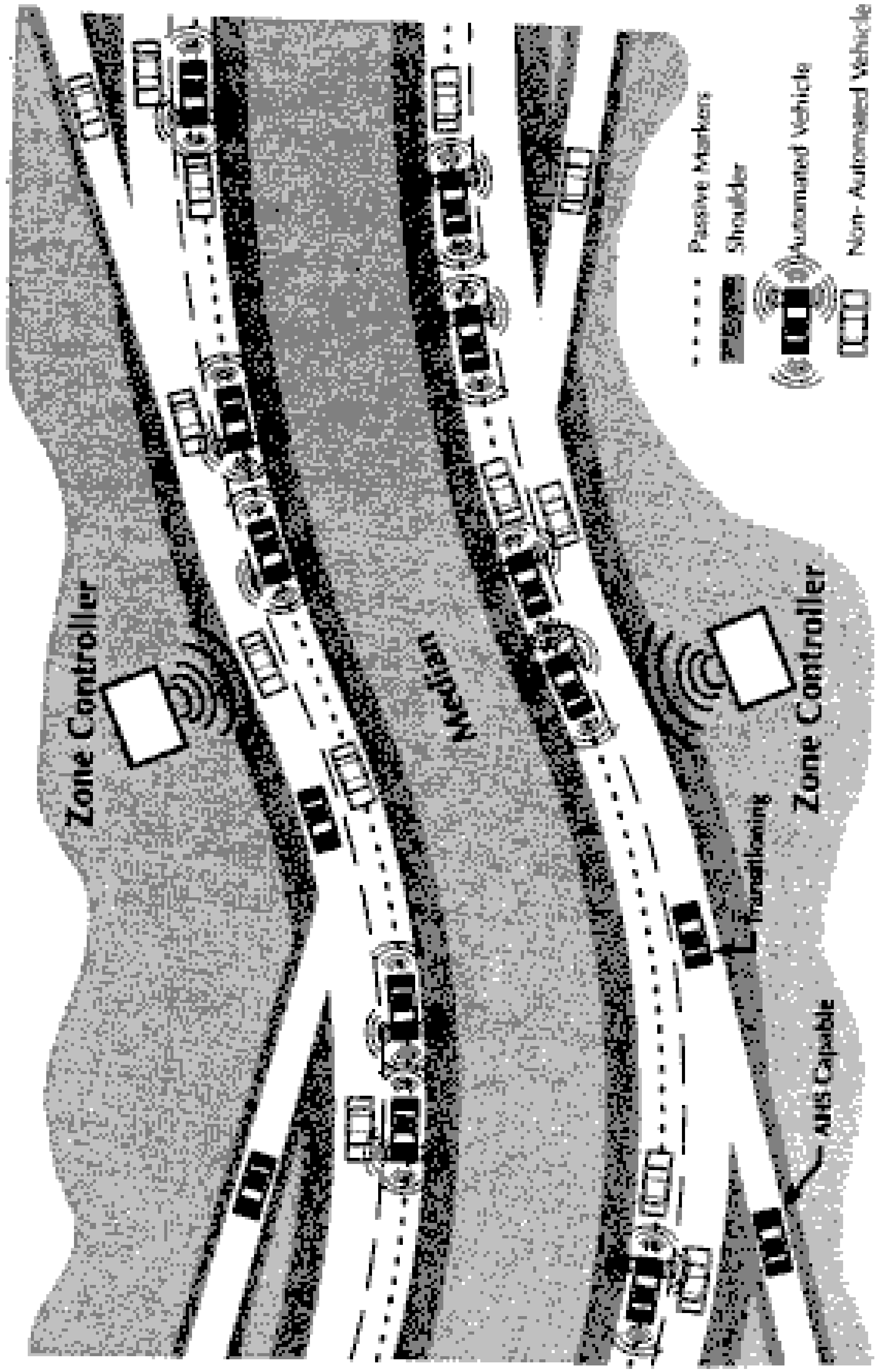


Figure 6. RSC 4.

Table 3. RSC assumptions

Parameter	RSC 1	RSC 2	RSC 3	RSC 4
Vehicle Type	Individual Passenger Car	Individual Passenger Car	Single Car Pallet, Automatic Control Only	Individual Passenger Car
Headway Policy	Uniform	Platoon	Uniform	Independent
Vehicle Intelligence	Good	Smart	Smart	Very Smart
Roadway Intelligence	Good	Average	Average	Dumb
Lane Configuration	Mixed traffic on inside AHS lane with manual traffic on outside lane	Dedicated AHS lane(s) with transition lane and manual lane(s)	Dedicated reversible AHS lane with pullover space adjacent to AHS lane	All lanes mixed traffic
Barriers	None	None	Between AHS and Non-AHS Lanes Only	None
Entry/Exit Ramps	Current Type	Current Type	Current Types for Non-AHS Dedicated for AHS	Current Type
Transition to AHS	Where: In AHS lane When: At driver command after sector control OK How: Manual switch	Where: In Transition Lane When: At driver command after sector control OK How: Manual switch	Where: In Pallet Attach & Detach Area When: Upon link to pallet How: Automatic with link	Where: In AHS lane When: At driver command after sector control OK How: Manual switch
Check-Out of AHS Vehicle Systems	Combination of periodic certification and polling of internal sensors	Combination of periodic certification and polling of internal sensors	Pallets under control of central authority—Inspected before allowing on AHS	Combination of periodic certification and polling of internal sensors
Failure to Transition Results In:	Driver must continue under manual control	Driver must continue under manual control in transition lane or re-enter manual lane	Essentially cannot fail to transition unless driver refuses to enter destination	Driver must continue under manual control

LITERATURE SEARCH

Introduction

A literature review was conducted to identify results of previous AHS, IVHS, and related research. A summary of this research was developed to provide a guide for ongoing research, prevent duplication of effort, and support the identification and analysis of urban and rural issues.

Four engineering databases were searched:

·TRIS.

·NTIS.

·INSPEC.

·Ei Compendex*Plus.

A total of 447 publications dealing with relevant topics were identified, and 146 articles were listed as meriting further investigation for task A. Seventy-two abstracts and 33 relevant documents were obtained and reviewed. Thirteen of these documents are cited specifically in this review. The remaining 20 were used for general reference only.

Specific information sought from the literature review included the maximum capacity (in vehicles per hour) that an AHS system could support, identified shortcomings, risks and/or feasibility of previously studied system configurations, and concepts that could be expanded to bring AHS one step closer to implementation.

Documentation in this section begins with a problem statement supported by data taken from the literature review. Then information is presented with respect to each of the six RSCs defined in a previous section. Both supporting and contradicting documentation is cited in the literature review. Because the RSC definitions are unique, only brief and general narration is provided.

Problem Statement

By the 21st century an improved traffic management system will be necessary to satisfactorily accommodate increasing traffic volumes on urban freeways. Congestion of the highway system in the United States is climbing steadily—an approximated 50 percent increase over the last three decades on urban freeways. Despite continued decreases in accident rates, there are still are approximately 40,000 fatalities and 1.7 million serious disabling injuries annually(1) leading to annual productivity losses of approximately $100 billion and another $137 billion due to traffic accidents. Forecasts predict increases in vehicle miles traveled (VMT) of 1.3 percent per year, vehicle hours traveled (VHT) of 1.7 percent per year, and vehicle hours of delay (VHD) at 3.6 percent annually.

The United States Department of Transportation (DOT), in accordance with the Inter-modal Surface Transportation Efficiency Act of 1991 (ISTEA), seeks a viable solution to accommodate existing and future travel demand. Automated Highway Systems (AHS) may help accomplish many of the goals set by ISTEA. Specifically, AHS serves to increase highway capacity and enhance safety, traffic mobility, and environmental quality. An operational AHS is to be ready for testing by 1997. Federal Highway Administration supports AHS feasibility, provided that the transition from the existing highway system to AHS can be made cost effective and practical in terms of impact on existing roadways and infrastructure.(2)

Special RSC Definitions for Urban and Rural AHS Analysis

Representative System Configuration 1

The first RSC combination considers average vehicle intelligence with uniform headways on a smart highway. Lane configurations contain three lanes per direction with the left-most lane striped and designated as AHS-only. No physical barrier separation is provided.

Research conducted in 1970 led the Ohio State University to adopt a uniform headway policy. A uniform headway approach was deemed most likely to feasibly remain collision free, despite lower highway lane capacities in comparison to platooning and pallet approaches.(3) This policy was specified on the precept that various planned urban mass transit systems could achieve maximum vehicle and occupant safety if collisions were minimized. A theoretical maximum capacity of 3,600 vehicles per hour per lane (vphpl) was specified for uninterrupted AHS flow (i.e., no interaction with merging or diverging vehicles). With extensive vehicle interactions, it was estimated that only 80 to 90 percent of this maximum could be attained.(3) Later work by Bender(4) concluded that the maximum AHS lane capacity would be 2,357 vphpl at 88 km per hour (55 mph). This value (actually only 65 percent of the originally perceived maximum capacity) also reflected a “collisionless” state of the automated highway with uniform spacing between vehicles. Vehicle spacing was determined by several factors, including:

- Reaction delay times.
- Vehicle speed.
- Vehicle length.
- Cruise velocity.
- Maximum levels of [system] failure.
- Controlled deceleration.

Merging and diverging maneuvers were assumed to reduce capacity by 20 percent.

Safety improvements from Bender's study concluded that AHS can eliminate the accidents caused by “improper driving,” which in 1979 accounted for 85.8 percent of all urban accidents and for 92.8 percent of all rural accidents. Bender also concluded that “AHS will effectively eliminate head-on and angle collisions, where closing speed contributes to their severity, as well as run-off-the-road accidents.”

A possible control configuration(5) for RSC 1 would utilize a control hierarchy wherein computers would manage travel at four different levels:

·Area-wide (network).

·Regional.

·Sector.

·Individual vehicle.

At the first control level, a centralized computer would oversee area-wide network operations within individual geographic regions of the automated highway network. Each regional controller (the second level of control) would communicate with smaller sector computers (the third level of control). The fourth, and lowest, level of control is that of the individual vehicle. Interaction between the sector controllers and the individual vehicles would be high. Four control points of the sector level may include:

·The desired condition of each vehicle.

·Determination of actual vehicle condition.

·Communications between the vehicle and sector controller.

·(Physical) Control of each individual vehicle.

Fenton, et al.,(5) indicate that to make this system work it will be necessary for cars to communicate both with other vehicles and with roadside communication devices. Furthermore, the vehicles must also possess capabilities to mix with non-automated vehicles. Such qualifications will be difficult to achieve without an “intelligent” vehicle. Use of an “average” intelligent vehicle introduces possible human error in highway automation and increases risk of accidents significantly.

In terms of vehicle control, measures of control between the highway and the vehicle for longitudinal and lateral control have been successfully tested with radars, beacons, cameras, and “wire-follower.” Much of this work has been done by either General Motors or Ohio State University. Results of various tests conducted on robotics in the automotive industry on navigation and vehicle control have also proven to be very promising at low risk to human safety.(6) Potential navigation technologies are discussed in greater detail by Smith and Starkey.(6) A final observation made by Varaiya and Shladover(7) revealed that given the commonalities between an average system and an intelligent system, and the eventual need to convert average to smart technology, supporting the cost relative to anticipated benefits for a partially automated system may not be warranted.

Representative System Configuration 2

The general concept behind RSC 2 is autonomous vehicle platooning. Three variations of vehicle platooning were adopted for analysis. Detailed descriptions of these variations are found the RSC Definitions section. For convenience, a few salient differences between RSCs 2A, 2B, and 2C are presented in table 4.

Extensive research on platooning of automated vehicles has been done at the Institute of Transportation Studies Extension Programs, University of California, Program on Advanced Technology for the Highway (PATH).

Table 4. Salient differences between RSC 2 variations.

Characteristic	RSC 2A	RSC 2B	RSC 2C
Roadway Configuration	3 lanes each direction	3 lanes each direction	2 lanes with reversible median
AHS Lane Location	Left lane dedicated	Left lane dedicated	Reversible median dedicated
AHS Lane Separation	None, striping and signing	Barriers	Barriers
AHS Exit/Entry	Mixed, use non-AHS ramps and merge from non-AHS lane	Dedicated AHS ramps	Dedicated AHS ramps
Access	Continuous, access all along AHS lane	Alternating, AHS ramps no more frequently than every other current ramp	Alternating, AHS ramps no more frequently than every other current ramp

One of PATH's primary goals is to provide a safe design for automated highways. Principles adopted by path to realize this goal include:(8)

·Use of automated vehicles only on the automated facility.

·Platooning of vehicles (not to exceed 20 vehicles per platoon).

·Use of barriers (high barriers between AHS and non-AHS lanes, low barriers between adjacent AHS lanes).

·Restricted movements (merging) of vehicles in platoons and of platoons themselves.

·Certainty of individual vehicle exit and entry.

PATH proposes 1-m spacings between each vehicle in platoons consisting of 10 to 20 vehicles. PATH's decision to pursue platooning stems from the potential increases in capacity and reduced collision speeds in event of a malfunction or accident. PATH estimates that the vehicle platoon system could increase highway traffic capacity by a factor of two or three with automatic control in the longitudinal direction.(2) Assuming 15-vehicle platoons, maximum capacity is approximately 6,000 vphpl at 88 km/h (55 mph). However, the probability of actually attaining a 15-vehicle platoon is low. Platoon sizes between 7 to 10 vehicles seem more likely, resulting in a maximum capacity of about 4,000 vphpl for the same speed.

Researchers(9) generally believe that integration of highway automation (and vehicle autonomy) must be done in stages beginning with vehicle navigation and route guidance information. These capabilities will lead to more highly developed information systems that can offer real-time parking, weather, and incident information. Adaptive traffic signals and freeway access control information will also become more readily available. The next step toward highway automation includes use of automated braking and accelerating capabilities (automatic cruise control) which use object detection devices to slow or stop a vehicle before collisions occur. This form of “headway control” (i.e., auto braking and accelerating) is expected to improve safety significantly by reducing angle collisions by 20 percent and rear-end accidents by 60 percent.(10)

The next stage may require the use of exclusive automated lanes for platooning and lateral control. Most of the technology would probably be in the vehicle although some kind of device may be needed on the freeway to provide lateral location information. Once the vehicle has entered the automated lane and joined the platoon, control of that vehicle is “given up” to the platoon leader. Manual capabilities are returned to the driver only when the vehicle has completely exited the automated lane.
Performing such maneuvers (platooning) will require complete vehicle autonomy. The system will maneuver the vehicle into the proper position without the aid of the driver, virtually eliminating the chance for human error, and consequently, reducing the possibility of accidents. Without actually constructing a prototype automated highway, simulation was concluded to be the most promising tool for studying proposed systems.(9) In the following paragraphs, findings of simulations similar to those configurations presented in RSCs 2A, B, and C are presented briefly.

RSC 2A: With a dedicated, left-most AHS-lane with no barrier and unlimited access, mobility improvements are evident on freeways and arterial streets. However, unlimited access allows greater numbers of vehicle maneuvers, which can reduce the capacity of the automated lane. Tsao, et al.,(11) assumed no physical separation between automated lanes and resolved that this configuration is particularly prone to intrusions of manual vehicles and other objects into the automated lanes of traffic--particularly in the event of an accident. He hypothesized that it would be necessary for on-board vehicle sensors to detect and recognize debris in the travel lane, and then to use this information to avoid collision. Such capabilities increases the complexity and cost of the system.

RSC 2B: RSC 2B includes exclusive access and egress ramps with barriers separating the automated and manual lanes. The presence of barriers would seem to improve safety of the automated lane by separating non-AHS vehicles from fully automated vehicles. However, Tsao, et al.,[11] recognize that the loss of automatic control in a platooning scenario presents a special set of challenges. They believe that barriers would restrict vehicle maneuverability in the event of a system malfunction; attached vehicles to the platoon could not avoid collision. The general response to this concern is that safety features can be built into the system to minimize the potential for malfunction. On the other hand, this near fail-safe system is presently non-existent.

Ramp separation distances become an important issue with AHS-designated access and egress points. Varaiya and Shladover[7] from PATH indicate that ramp separation distances are dependent upon the time required to merge, change lanes, enter the automated lane, and join a platoon. This time is dependent upon the number of lanes, amount of traffic on the freeway and speed of vehicles in the traffic stream. Anwar and Jovanis[9] used accident data in California to determine where (in relation to ramp locations) accidents occur most frequently on freeways. They observed that sideswipe and hit object accidents occur most frequently within 50 m (164 ft) of the on/off ramp locations. They suggest that distinct grade separated ramps be used for automated lanes, rather than risk operational disruptions due to accidents caused by merging and diverging manually-controlled vehicles.

RSC 2C: In this system configuration, the vehicles will have exclusive access ramps and barriers separating the automated lanes from non-automated lanes. This type of facility operates similar to reversible High-Occupancy Vehicle (HOV) lanes today. Studies done by PATH have demonstrated the effectiveness of this type of system.[10] They propose that roadside computers coordinate the flow of traffic by sensing congestion and then relaying that information to each vehicle's on-board computer. Tests conducted by Path included a two-vehicle and a four-vehicle platoon. PATH reported that the actual riding quality during the tests was so smooth and impressive that the following car gave the impression of being rigidly linked with the leader. These successful results inferred that a human's ability to manually control the vehicle could not match the speed changes within the stringent guidelines of the testing scenario.

<u>Representative System Configuration 3</u>

This RSC utilizes “smart” pallets to transport non-AHS equipped vehicles on an ”aver-age“ intelligent highway. The appealing feature of this configuration is that virtually all vehicles can use the AHS by simply “piggy-backing” onto a smart pallet. General Motors[12] conducted a feasibility analysis of potential AHS traveling unit types, of which pallets were considered. Of all traveling unit types considered, the powered multiple-vehicle full pallet received the only overall poor rating. This rating was attributed to the several characteristics of the pallet concept:

·Access/egress delays.

·Limited interchange capability.

·Greater land requirements.

·Higher operating costs and reduced energy efficiency due to transport of empty pallets.

However, a single-vehicle partial pallet and a single-vehicle full pallet system were deemed appropriate for some AHS applications (e.g., to be used during the transition period from partial automation to full automation with all vehicles).

A pallet system essentially eliminates the possibility of human error, thus improving safety and lessening the potential for accidents. Today, a quasi representation of a pallet system is evidenced by the planned system for moving autos through the English Channel Tunnel.(13) Officials feel that minimizing the potential for human errors (incidents) that may threaten access to the tunnel is worth the added costs and efforts. Similar applications may be appropriate in AHS such as vehicle passage through freeway bottlenecks, narrow bridge locations, or other capacity restraining features. Maximum capacity (3,600 vphpl) for uniformly spaced, single-vehicle pallets would be similar to that for uniformly spaced, fully automated vehicles.

Representative System Configuration 4

RSC 4 considers independent headway spacing with mixed autonomous vehicles and non-autonomous vehicles on passive freeways. With this concept, AHS-equipped vehicles are permitted to operate virtually independently of the highway infrastructure. Potential use of magnetic nails or painted lines on the highway, may assist the vehicle in guidance maneuvers; no active infrastructure technologies would be necessary.

Potential characteristics of this configuration include a combination of autonomous vehicle maneuvers following manual commands. Headway spacing and lane integrity would become autonomous maneuvers once the driver chooses a desired lane for travel, or the entire process could be done automatically. Tsao, et al.,(11) reports that this configuration is of great interest for three reasons. First, autonomous vehicle free agency represents a step in the evolution from the present transportation system (manually controlled vehicles) to fully-automated vehicles. Second, this type of system is already under development in Europe. Finally, autonomous vehicle free agency introduces many of the same human factors issues as the more highly automated AHS concepts, such as transition to and from automated control. Vehicles in this scenario may be prone to failures in transition of control from the automation back to the driver. Thus, human factors considerations will be crucial to its final design.

Benefits gained under this configuration seem mostly directed to individuals on-board the vehicle. Use of navigation technologies would likely lessen the chance for accidents, although lane capacities would still be dependent upon non-automated vehicles. Present maximum capacities on existing freeways is about 2,200 vphpl.

WORKSHOPS

Introduction

Intelligent and automated highway systems represent very recent technological innovations. However, it appears that analogies can be drawn to existing fixed guideway transit, HOV, and advanced freeway traffic management systems. Therefore, to promote a working dialogue within the industry and identify issues associated with the deployment of AHS in either an urban or rural environment, a series of workshops attended by senior transportation professionals were held. This chapter describes the workshop format and attendees and the issues and risks identified at the workshops.

The first workshop to discuss the issues and risks of AHS deployment was conducted on January 8, 1994 as part of the annual meeting of the Transportation Research Board (TRB). The workshop was held at the Sheraton Washington Hotel in Washington D.C.

Invitations were sent to more than 400 transportation professionals. The invitation list was developed from IVHS America mailing lists with input from the FHWA AHS study team. A total of 72 professionals representing State and Federal transportation agencies, industry, auto makers, and academia attended the workshop. The attendance list is included in the appendix.

The workshop agenda included an overview of the AHS development program and technology, a presentation of urban and rural AHS issues, and a small breakout group session. The breakout groups were given the following set of issue areas to discuss:

- Institutional issues.
- Society issues.
- AHS development.
- Candidate sites.
- Access.
- Technology.
- Deployment and evolution of AHS.
- Non-AHS impacts.

Note that a variety of issues were discussed beyond the focused issues of urban and rural characteristics. Given the difficulty of assembling a group of highly competent transportation professionals, the decision was made to expand the purpose of the workshop to include a diverse set of issues. This benefited the entire AHS research program without deterring from the main focus of the workshop.

The second workshop was held On June 21, 1994 in Minneapolis. The agenda focused on the key issues of potential capacity improvements in urban freeways and safety improvements in both urban and rural areas. Approximately 25 professional representing the Federal Highway Administration, the Minnesota Department of Transportation and the project team attended this workshop.

Issue Analysis

Breakout groups at the first workshop (at TRB) were given a list of issue areas and a specific question to discuss. The second workshop (in Minneapolis) was dedicated to discussing traffic operations and safety issues. The following sections summarize the input received from the transportation professionals for each area.

Institutional Issues

Who should develop, fund, construct, and operate an AHS?

The Federal Government is a logical starting place for AHS development. The current federal aid process works well and could be a model for AHS implementation. Some automated highway systems may be implemented with private sector funding such as toll facilities, but federal programs are anticipated as the major source of funds. In any event, public/private partnerships are encouraged for AHS implementation.

Public/private partnerships, however, are usually not easily derived because conflicting interests. The private sector generally desires low risk investments, profitability, and a positive return on their investment. The public sector generally desires safety and equity of accessibility. While safety and accessibility are important issues to the private sector, they are the primary focus of public sector.

Provisions of “guaranteed” human safety generally come at higher costs due to added redundant features built into the product. Because the potential loss of human life exists, an AHS product comes with high risk. These factors cause private sector investors to hesitate to enter into such relationships. One potential option would be a private rollover of the AHS, i.e., start publicly then turn operations management over to a private company.

It was discussed by all groups that no single source would be feasible to develop, design, fund, construct and operate an AHS facility. Rather, it was suggested that multiple combinations of Federal, State, tolls, consumer, and developer contributions would be necessary. Such complexity raises doubt as to whether an AHS system can ever overcome problems inherent with these crucial relationships. Others feel that these problems can be worked out over time. Commercial carriers were identified as perhaps the most likely and willing organizations to participate in pioneering AHS partnership efforts.

Construction of a new, national AHS was considered highly doubtful. Rather , it was suggested that the existing infrastructure would be modified to accommodate AHS. Therefore, it was expected that AHS systems would be publicly funded. Under this scenario, funding would come from the public, government fees, and tax money. This is in contrast to IVHS America, which assumes future technologies to be funded from 80 percent private and 20 percent public sources.

Additional institutional issues raised include: Do non-AHS users also pay for the system?; Who are the partners to be included, and what compensation is desired by them?; Will only the rich be able to afford use of the systems?

Society Issues

What is the perception of AHS in the professional communities and the general public?

The transportation professionals generally understood the potential benefits an AHS could bring to the transportation industry. However, given the present inefficiencies in today's transportation industry, many doubt that AHS will ever be implemented. Stated another way, how can we advance to a higher-order transportation mode when we haven't mastered our present conditions? Also, there is concern about the benefits and costs associated with AHS. If AHS is successful, greater numbers of vehicles could be making trips causing an increase in overall vehicle miles traveled. If unsuccessful, the cost to implement the system would be perceived as having been wasted. For these reasons, AHS is sometimes viewed as an infeasible alternative despite the general acceptance of IVHS technologies overall.

Media people perceive automated highways to be a form of “Buck Rogers” pageantry; lots of high hopes and fantasy thinking, but resulting in nothing of tangible merit. Dealing with this perception is important due to the influence media can have with the general public.

The general public is expected to receive AHS with respect and caution. Although perhaps fascinating, AHS was expected to create an uncomfortable driving environment for most drivers. Vehicle headways of a meter or less at 88 km/h (55 mi/h) or more can create uneasiness in a driver. Furthermore, high technology is not often received immediately by the general public, particularly by those individuals who are not computer-literate. In these instances, high technology can be met with much resistance. Further resistance is expected if AHS is viewed as a service only the rich can afford.
All groups concluded that some form of government-sponsored public education program or campaign was needed as a precursor to AHS implementation. Given the importance of private sector involvement, the emphasis of marketability in the private sector, and the influence of public opinion on a product's marketability, some participants stressed public education as the single most important issue regarding AHS. In the early stages of a demonstration project a critical link in the development of an AHS is lost if the public does not perceive positive benefits of the system and become convinced of the value of an AHS. This could severely limit the development of an AHS.

Safety is an area that can directly impact public acceptance. Proven safety features in automobiles have been observed to increase a vehicle's marketability. Conversely, providing increased safety features increases a product's cost, which can decrease marketability. Dichotomies of this nature cause designers to weigh the sum of advantages and disadvantages when determining feasibility. It was stated that the net benefit must be rather significant to warrant the increased cost. This phenomena will need additional analysis for AHS.

Caution should be used when determining the congestion benefits of AHS because congestion is perceived differently by different people. Vehicle accidents, however, are very visible and noticeable. If AHS is able to significantly reduce the number of accidents such that the public can observe a difference, then acceptance of an AHS is more likely. The benefits need to be significant to justify developing a new system.

AHS Development

What is the most important issue to be resolved before automated highway systems are implemented?

Several issues were raised as “the most important concern” to be resolved. Many issues raised overlap one another. The following is a compilation of issues with no hierarchy of importance given or implied.

- Reliability

  The system must demonstrate that the technology is safe and functions properly under many different situations and weather conditions. Several backup features must exist such that the system remains operational given partial failure of various components. The public must be convinced of this reliability.

- Vehicle Control

  Mainline control is virtually a given, but entry and exit vehicle control can be difficult. Many issues can be raised here, such as, merging maneuvers, single vehicle entry vs. platoon entry, source and type of intelligence monitoring the exit and entry maneuvers, etc.

- Public Acceptance

  As mentioned earlier, without support of the traveling public, AHS has little chance of being accepted as another way to travel. Linked to this issue is a public education and information program. It is emphasized that the developers of the AHS *listen* to the public's concerns and work toward satisfying their needs. This process is marketing of AHS.

Another aspect of public acceptance is whether the public can afford use of the AHS. Affordability refers to both the purchase and maintenance of essential AHS equipment. Affordability is also tied to a benefit/cost evaluation.

- Benefit/Cost Evaluation

  Both quantified and qualified measures must be defined and evaluated before committing large amounts of resources and money to AHS development. Some propose that these evaluations occur before any additional efforts are undertaken, and that they be done in incremental pieces such that only the resulting beneficial attributes of AHS be advanced.

- Feasibility of AHS as a Business Risk

  Given the likely 80 percent private, 20 percent public funding scenario of AHS, AHS feasibility must be approached as a business investment. Likewise, if deemed infeasible, treat it as such. Group members recognize the large amount of effort required to develop and implement an automated highway system. It is important to minimize the risk of wasting large quantities of resources on a product whose anticipated return rate is positive only after a couple of decades.

- Liability

  Many different liability-related questions have been raised about AHS. Perhaps the biggest question is who will be liable should errors in the system occur? Is it the government or the private developer? These questions likely lead back to the funding source of the AHS. Is the funding agency the liable party? Because many of these issues have not been resolved, much more definition and system specification is needed.

- Environmental Issues

  The potential for AHS to increase vehicle miles traveled raises environmental concerns. Air quality, noise, and congestion all impact the quality of life and the environment around us. Modeling of impacts and mitigation of adverse effects must be considered in the development of automated highway systems.

- Human Factors and Vehicle Automation

  An issue linked to liability is the degree of control a driver has while within the automated highway system. A fundamental assumption would be that a monitoring system would oversee the human's condition. To date, no specifications for how the monitoring system would function exists. How much responsibility should remain with the operator? What degree of automation is “optimal” given partial human control? Another outstanding problem is that AHS will not eliminate motorist-alcohol problems. DWI and DUI issues could impact the degree of control drivers are allocated in AHS.

- Future Alternative Fuel Vehicles

  Given Federal mandates of clean air standards, many alternative fuel automobiles are presently being developed. Electric vehicles are strong possibilities for future commuting traffic. AHS development must consider use by these vehicles as well as the standard fossil fuel vehicles. While it is difficult to accurately predict the future, some foresight is needed to build in flexibility into the AHS.

- Resource Allocation

  At both the Federal and State levels, AHS development and construction is competing with other transportation research, construction and maintenance programs for funding. Continued funding for AHS will be dependent upon immediate, visible benefits. Congestion pricing may become more attractive, even to the point that roadways become franchised. Road pricing (toll facilities) is likely to be a source of funding.

- AHS Model of Success

  The Apollo program was suggested as a model of success for the AHS program. The AHS program, however, was thought to be twice the effort and technology of the Apollo program. The Apollo program had a champion in President Kennedy. Who will be the AHS champion?

  The salient message here is that success in the past has been dependent upon a champion, or a publicly perceived champion, and the funding to support that calling. AHS needs a champion and funding support to be successful. Neither of these are apparent today.

- Standards of System Architecture

  Because participation levels will vary from state to state, system architecture standards are absolutely necessary to ensure system-wide compatibility. Without such standards the risk of wasting resources and funds is very high.

<u>Candidate Sites</u>

What possible deployment sites would benefit from an AHS? What benefits would potentially be realized?

All groups concluded that regardless of the site, success of the initial system was imperative for public acceptance. Characteristics of a successful AHS site include:

- Traffic Congestion

Urban sites must include paralyzing traffic congestion levels such that the practical benefits of AHS can be immediately felt. This item is closely tied to public acceptance of the system.

- Section Length

  A minimum of 10 to 20 mi are recommended so that users get a feel for how the system operates. Also at these lengths, travel time savings greater than 5 minutes are achieved and noticeable to travelers.

- Separated Facility

  An exclusive ROW, or reserved or protected areas such as HOV facilities is desired. The impacts of possible system failures are lessened if restricted to a separate facility.

- Rural Environment

  Rural environments have interchanges spaced miles apart. Less traffic exists there, and consequently the likelihood of accidents is less. However, rural environments typically do not have paralyzing traffic congestion levels.

- Non-Environmentally Sensitive

  There is no intention to discredit the importance of environmental issues, but rather to place the first AHS in an area where environmental issues do not preclude its implementation. Rationale behind this item stems upon proving that the technology works properly, and then modify the technology to fit appropriately into a given environment.

- Automobile-Dependent Audience

  AHS is predominantly focusing upon auto users as marketshare. For evaluation purposes, an auto-dependent audience would offer insights to the marketability and perhaps degree of public acceptance AHS may have.

- Variable Weather Conditions

  A wide range of weather conditions must be considered for the AHS. A candidate site should provide variable weather conditions of heat, cold, wind, rain, and snow.

- Agreeable Community

  During an operational test of AHS, researchers must have complete and unconditional use and accessibility to the facility. This item is mentioned based upon experience of the PATH program on I-15 near San Diego, California. PATH could only use the existing HOV facility for a few off-peak afternoon hours per day. Many commuters also complained about the roadway being closed off temporarily during the research.

- No Legal Barriers

  The initial AHS must be viewed strictly as an operational test such that legal barriers are eliminated or held to a minimum. Researchers and system developers, though meticulous in providing safety, require some room for error in experimentation—such error must be free of potential legal ramifications.

- Data Availability

  In order to observe improvements attributed to AHS, candidate sites should have accurate accident records available. Safety analyses depend upon this information for complete analyses to be conducted.

- Large Truck Population

  Given the potential acceptance of AHS in commercial carriers, a candidate site should include traffic streams with high percentage of trucks.

- Traveler Trip Characteristics

  Candidate sites should reflect travelers' preferred transportation mode and purpose. A primary advantage of AHS is that the traveler remains in their vehicle throughout the trip.

  Typically, the private automobile is the preferred mode of travel. When traveling long distances, however, an alternative mode may be desired, such as an airplane. AHS may capture a portion of those travelers. Thus, candidate sites may link two major metro areas whose connecting trips are predominantly served by a transportation mode other than the automobile.

- Potential Sites

  Suggested sites include the following:

  - Santa Monica Freeway, California HOV-lane.
  - Taxi Cab fleet in New York City.
  - Southwest Virginia Smart Highway.
  - US 101, San Francisco, California (subscriptions potential exists).
  - I-10, Tucson to Temp, Arizona.
  - I-95, New York City to Washington, D.C.
  - I-10, Phoenix to Los Angeles.
  - Metropolitan areas to recreational sites (e.g., beach, amusement parks, etc.).
  - I-35, Minneapolis/St. Paul, MN.

Opinions were split as to whether the first automated highway system should be placed in an urban or rural environment. All generally agreed that AHS as a congestion relief and accident reduction measure would be useful. This would benefit a congested urban environment. However, the rural environment was suggested as a better proving ground to test new technology because of lower traffic volumes, generally wider cross sectional areas and right-of-way, and lessened vehicle weaving.

It was suggested that, because of latent demand, any measurable improvement attributed to AHS in the urban environment could potentially increase the risk of creating a supersaturated transportation network. Others argued that AHS requires a separated facility such as an HOV facility, which is only found in high population density urban or urban-fringe areas.

As presented later, AHS deployment can be done incrementally. Perhaps the incremental deployment of AHS begins first in the rural environment and then moves into the urban-fringe and urban environments. In this way, lessons learned from the less complicated rural environment may be directly applied to the urban environment.

Access

What are some of the major issues with providing access to AHS?

Major issues regarding access to AHS include:

·Physical Issues

> Geometric configurations of on and off ramps may need to be altered along AHS facilities. Engineering and construction costs can be very high, particularly if safety concerns mandate new standards in highway design. Also, is an inside or outside lane configuration best for an automated highway system?

·Authorization

> Are all vehicles allowed on the AHS or just a select few based upon special features? Serious consequences can result if only the “rich” can use the system.

·Enforcement

> What is the penalty for violators? How is proper access guaranteed? How is wrong-way access prevented?

·Coordination with CBDs

> Automated highways optimally would link major CBDs together. Access issues must consider the possibility of providing access directly to these areas as an alternative to just releasing the vehicles onto the arterial street network.

·Ingress/Egress Merging Techniques

How does a vehicle enter or exit the AHS? Are platoons or individual vehicles used? Much of this evaluation is dependent upon whether the AHS is located on the inside or outside of existing freeways.

·Spacing of Access

AASHTO has established general guidelines for interchange spacing for urban and rural areas. Should these guidelines vary given existence of an automated highway?

·System Diagnostics

This issue considers vehicle owner maintenance and mandated maintenance economics. Not only will the system require highway-to-vehicle verification of AHS compatibility, but the vehicle and highway “smarts” themselves will require system diagnostics to verify that they are functioning correctly. These diagnostic capabilities will likely incur costs upon both the vehicle and system owners--costs which they may have no choice but to pay.

·Safety

Of greatest importance is the ensured safety of drivers and their passengers. Automated systems and partially automated systems must provide safe access to and egress from the AHS.

·Maintenance and Closure Mitigation

Considerable effort is needed to determine maintenance procedures for AHS access points. If for any reason the access point must be closed, alternate routes and plans must be ready.

· Transportation System Interface

The access locations should coincide with existing and planned roadways and land uses. These locations will likely impact the arterial and collector street network, and require new signal timing plans. Land use planning must also accompany evaluation of this issue.

·Priorities

Do you first build the infrastructure or equip the vehicles? If you build it, will they come?

Technology

What are the major technical issues and risks associated with deploying an AHS?

The overlapping of issues should become more apparent in this section. Technology issues were intended to focus on the physical and tangible elements of the system. Issues identified follow.

·Reliability

The public will quickly criticize and stop use if the AHS is not reliable under virtually all circumstances. Weather is of particular concern. For example, how will snow removal occur. Are automatic snow plows planned?

·Exit/Entry

It is believed that the greater the degree of automation, the easier exit and entry will be. Complete development of a fully automated highway has never been accomplished. Consequently, it is not known how long it will take to enter or exit the system.

·Funding

The risk of insufficient public funds is very real for AHS. Given the large anticipated costs, the public sector will probably not completely pay for the infrastructure. The private sector may be better equipped to financially support AHS. Toll facilities or congestion pricing schemes may be used as a private financing methodology.

·Litigation

Small airplane manufacturers were cited as an example of what could happen to AHS producers in the event of accident on the AHS. Small airplane manufactures could not afford the necessary legal costs and insurance and consequently, few if any small airplane manufacturers still exist. Similar risk may exist for developers of AHS-ready vehicles and technology. Therefore, involvement in litigation for AHS developers, manufacturers, and operators is a distinct possibility.

·Developer Product Liquidity

Developers must be able to move products and minimize unnecessary inventory. Thus, developers will be challenged to find the balance between customer demand and their produced supply. The risk of developers being stuck with large inventories is real.

·Employee Migration and Retention

Does AHS support urban and suburban sprawl? How will AHS impact existing and future employment centers? Developers must recognize that an AHS can cause dramatic changes in commuter behavior and employment centers.

·Proprietary Intelligence

Copyrights, proprietary information and products will result from private investment of AHS. Because not all funding is likely to originate from the private sector, claiming proprietary intelligence as a result of a publicly funded project may have legal consequences. Also, given the magnitude of the automated highway system program, no one organization will be able to design and develop it alone. Sharing of proprietary information between private competitors is even more difficult than getting that same information to pass from private to public hands.

·Redundancy versus Safety

What degree of redundancy is necessary for AHS? When do the costs of redundancy outweigh the benefits? AHS is not anticipated to require the same degree of redundancy as defense systems but will probably be higher than most commercial or industrial systems. It will probably require many fail-safe features which historically have led to large system costs.

·Infrastructure

Are separate AHS facilities necessary or can existing facilities be modified? Does AHS require the full pavement width, or can a form of guideway or ribbon-strip pavements be used? What quality of pavement and barriers are used? What impacts are likely to occur during rehabilitation of an AHS? Where are the electronics and communications elements located? Will the presence of these elements impact present highway and drainage design standards? Will additional ROW be necessary?

·Safety Certification

New criteria and standards must be created for AHS vehicle certifications. These criteria may vary from state to state, but hopefully follow the same basic architecture.

·New Legislation and Politics

Implementation of automated highways will probably require new state and federal legislation. Such legislation can often require years to become law.

·Human Factors

Changing from manual mode to automatic mode is a critical issue. What type of media or communication device is required to return a driver from a deep sleep to complete alertness? Given that drivers have different ages, experiences, and driving abilities, can one system accommodate such a broad audience? How are drivers alerted about animals crossing the facility while in travel? Can drivers and their passengers ever be completely free of fear from an AHS breakdown?

·Continuity between Urban and Rural Design

It will be difficult to create a “seamless” automated highway system between urban and rural environments. These environments are very different from one another, and each could require separate consideration in development and design.

- Sensor Interpretation

  It is a formidable task to tie vehicle and infrastructure intelligence together accompanied by all necessary safety and redundancy features. Even though some of the technologies exist today, they have not been tied together on such a large scale.

Deployment and Evolution of AHS

What are the major deployment issues and risks associated with placing an AHS in an urban environment? In a rural environment?

- Urban Environment

  The urban environment provides the greatest potential benefit for AHS in terms of congestion mitigation, reduced accident, reduced travel times, and fewer emissions per vehicle compared to idling. These benefits exist because urban areas typically have much higher traffic volumes and accompanying congestion levels. Despite these potential benefits, these same features hinder possible deployment of AHS in the urban environment due to the complexity of the required system architecture and design. Acquisition of additional land is also extremely expensive in urban areas. Much communication, coordination, and cooperation is required when dealing with multiple agency, city, county, and state representatives. Consequently, flexible and prolonged time lines are required.

- Rural Environment

  The rural environment is more conducive to demonstration and implementation of AHS because there are fewer vehicles, fewer conflicts with adjacent land uses, and longer distances between access points. Right-of-way acquisition is also cheaper in a rural environment than in an urban environment. The difficulty with a rural system is in convincing the public of the potential benefits of AHS given the potentially high costs. Justifying the cost per user in a rural environment could be difficult. Safety was expressed as a concern in rural environments. For example, how is wildlife prevented from wandering onto the roadway. Another example is how to account for vehicle lane drifting during operation.

What steps should be taken to evolve highways from current to fully automated highways?

AHS should be developed incrementally as technologies evolve beginning with vehicle technologies. Most professionals recognized that all the required technologies for both vehicles and the infrastructure are not available. An incremental deployment will promote public acceptance since each step could be smaller with less impact. This approach allows the project's scope to change over time and adapt to changes in technology. This method applies to both the AHS infrastructure and vehicles, including mass transit vehicles, to utilize the infrastructure.

One proposed evolution of on-board vehicle AHS capabilities is as follows:

- Automatic braking capabilities.
- Automatic cruise control.
- Lateral and longitudinal control.
- Exit/entry and merging capabilities.
- Trip management.

Infrastructure evolution would accompany the development of the on-board vehicle equipment. In this scenario, infrastructure design and engineering could be taking place during the development of automatic braking and cruise control. As the lateral and longitudinal control capabilities emerge, construction of the required supporting hardware could be accomplished. For example, magnetic pins might be embedded in the freeway or special types of barriers may be added to roadways to act as guides for control sensors on the vehicles. Finally, overall system control would be developed to manage all trips within the AHS network. This final step would include the development of a super computer and trip manager. Smaller subsystems may operate under the domain of this governing system, but ultimately the “mother” computer would regulate and optimize system use.

Obviously, the complete realization of this scenario is an ambitious endeavor--even if resources were unlimited. This observation only further supports breaking down the AHS program into smaller, achievable steps which all add to the completed system. As time progresses, new and improved technologies will emerge, and so will the completed automated highway system as a whole.

Coordinated efforts between Federal, State, county, and local government agencies is also essential to successful deployment of AHS. Issues regarding payment for operation and maintenance must be addressed, as do the liability issues. Some feel that these responsibilities will lie where the AHS is placed. If this assumption proves true, some agencies may not support AHS.

<u>Non-AHS Impacts</u>

What are the implications, issues and risks for the non-AHS roadway systems surrounding an automated highway system?

·Equity

Some motorists may see the AHS in operation, but be denied use of it. Denial could result from several reasons including lack of personal income, inadequate vehicle "smarts," geographic location/placement of the AHS. Those denied access to the AHS may feel cheated and treated unfairly treated, especially if the AHS is publicly funded.

·Accessibility

An assumption of AHS is that in order to provide the greatest benefit, access points must be separated sufficiently such that traffic flow is minimally disrupted. This characteristic can also hinder its use because of the difficulty for some drivers to reach those access points.

·Construction and Land Acquisition

Many of the same issues and problems associated with building highways today will exist with additional construction of AHS. All of the social issues, land use impacts, residential and/or business relocations, etc. will still be present with AHS.

·Adjacent Feeder and Distribution Roadway Network

How will the adjacent roadway network accommodate the now double or triple amounts of traffic generated by the AHS? Congestion will definitely be a problem near and around these access points. Moving the traffic efficiently to and from the ingress/egress points will be a new challenge as well.

·Parking

Where will the additional vehicles be stored during the day? Commuter traffic may get downtown quickly only to lose the time savings in searching for parking.

·Environmental Issues

Noise and air quality will be impacted near and adjacent to the facilities. The AHS could also impact significantly present travel patterns, causing impacts in areas that presently may not have environmental problems.

·Insurance

New types of insurance and liability coverage may result from AHS. Linked to these changes will likely be increased insurance premiums. Are these premiums mandated to all, or just those using AHS?

·Funding

How will the distribution of available funds be allocated if AHS is taking the greatest portion? What are the impacts on other state, county, city, local streets and highways? What about operating and maintenance costs?

- Land Use Impacts

  Parallel roadways will likely see reductions in traffic, which may not be well received with existing commercial developments. Other real estate will also be impacted.

- Urban Traffic Impacts

  Staff from the Minnesota Department of Transportation's (Mn/DOT) Traffic Management Center presented information relative to the implementation and results associated with deploying an advance freeway traffic management system in the Minneapolis-St. Paul area. The key components of this system include the following items.

  - Vehicle detectors.
  - Surveillance.
  - Highway advisory radio.
  - Metered ramps (and HOV Bypasses at selected locations).
  - Changeable message signs.

Mn/DOT began constructing their traffic management system in the early 1970's and to date have deployed approximately 3,000 vehicle detectors, 150 closed circuit television cameras, 300 ramp meters (40 with HOV bypasses) and 50 changeable message signs along approximately 170 mi of the metropolitan area freeway system. All of these features plus an area wide advisory radio system are directly linked with the Traffic Management Center in downtown Minneapolis. The total cost of this system is approximately $30 million or $175,000 per mi.

The significant conclusions of Mn/DOT's presentation include the following:

- The application of freeway traffic management strategies has resulted in a 25 percent reduction in mainline delay and a 30 percent reduction in accidents.
- The overall capacity of the freeway system has been increased as a result of a uniform 10 to 15 percent improvement in the per lane capacity (from 2,000 vehicles per lane per hour to almost 2,300 vehicles per lane per hour) and isolated cases of increases in the range of 20 percent.
- Freeway capacities in excess of 3,000 vehicles per hour per lane are unrealistic.
- The characteristics of vehicle and (incident detection and management) and benefits (increased capacity, reduced delay and reduced accidents) of proposed AHS systems are similar to those for existing freeway traffic management systems. As a result, it is reasonable to use the traffic management systems as a model for

forecasting capacity, delay and safety benefits associated with the implementation of an urban AHS system.

·Rural Traffic Safety

Mn/DOT staff understand the potential benefits associated with implementing advanced traffic management and control strategies in urban areas. However, they were unsure how advanced technologies could be applied to rural transportation needs and concerns. As a result, Mn/DOT's office of Minnesota Guidestar conducted a federally funded study, the Rural IVHS Scoping Study. The objective of the study was to assist in determining the role of advanced traffic management strategies in Minnesota.

The rational for trying to understand rural transportation needs and how to address them is based on the following facts:

- 48 percent of Minnesota's population lives in rural areas.
- 89 percent of the road mileage and 53 percent of the vehicle miles traveled in Minnesota occur on rural roads.
- 73 percent of 1992 fatal crashes in Minnesota occurred on rural roads.

The transportation needs of rural motorists were determined by asking them at a series of nine regional meetings and six focus groups. Information about safety, weather and road conditions, congestion, emergency services, transit usage, commercial vehicles and economic development were gathered in a qualitative method. This information was then verified by quantitative methods thru the use of a telephone survey of 455 Minnesota resident and 50 tourists who had travelled through rural Minnesota during the past two years.

The key result of the study identified two major themes:

- Improved traffic safety.
- Increased accessibility to road and weather condition information and emergency services.

One additional key point was documented in the study, 76 percent of the study participants identified user fees as the appropriate method of paying for new services and products.

RESEARCH AND ANALYSIS

Introduction

The methodology used to compare the urban and rural implementation of AHS included research and analysis of technical and operational issues and the identification of opportunities and risks by freeway area type (urban/fringe/rural) and RSC (figure 7). The analysis was conducted for only freeway-type roadways because it was assumed that the initial AHS implementation would be on a freeway. However, it is expected that some or all of the AHS technologies could also be exported to other roadways and that the conclusions of this analysis would remain valid for either freeway, expressway or arterial implementation.

The urban, fringe and rural freeway area types were defined by categorizing the freeway segments within the State of Minnesota based on cross-section, interchange spacing and average weekday traffic volume. Data from the State of Minnesota was chosen because the Minnesota Department of Transportation (Mn/DOT) has comprehensive and accurate data on a number of the topics considered for analysis and because this data is expected to be representative of average traffic conditions throughout the nation.

The general definitions of the three freeway area types are provided below.

Urban

More than two lanes in each direction separated by a median barrier, average weekday traffic (AWT) volumes greater than 80,000 vehicles per day (vpd) and interchange spacing of 0.8 km (0.5 mi) to 1.6 km (one mi).

Fringe

Two or more lanes in each direction separated by a median barrier or ditch, AWTs between 20,000 and 80,000 vpd and interchange spacing of 1.2 km (0.75 mi) to 3.2 km (2 mi).

Rural

Two lanes in each direction separated by a median ditch, AWTs up to 20,000 vpd and typical interchange spacing of 4.8 km (3 mi) to 8 km (5 mi).

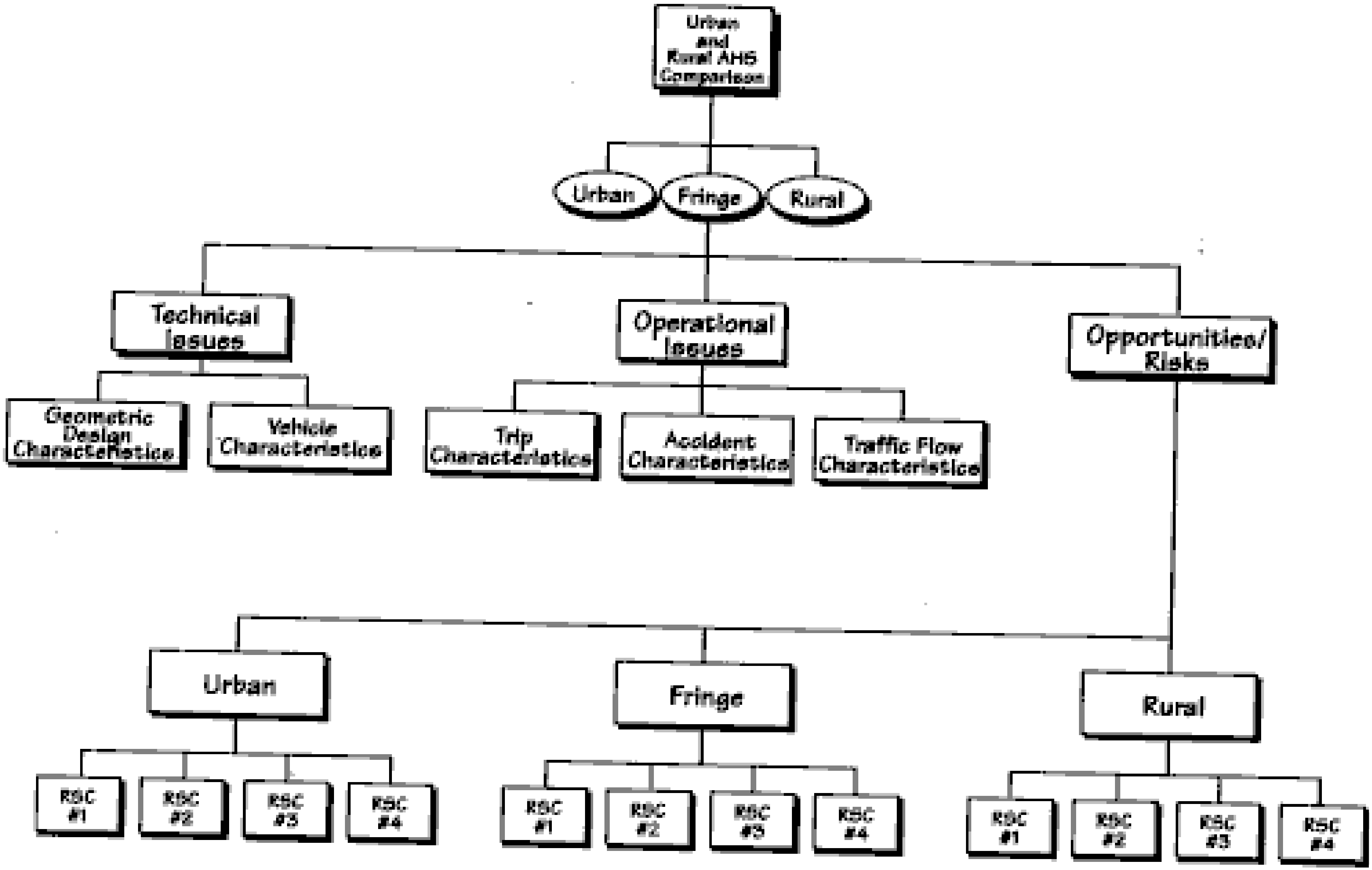


Figure 7. Task A methodology.

Based on these definitions, each of the interstate freeway segments within the State of Minnesota were categorized as either urban, fringe or rural. The individual segment designations are shown in figures 8 and 9 and listed below.

Minnesota Urban Freeway Segments

- I-94 from US Highway 61 to Minnesota Trunk Highway (MnTH) 100.
- I-35E from I-94 to MnTH 36.
- I-35W from MnTH 62 to MnTH 36.
- I-394 from I-94 to MnTH 100.
- I-494 from MnTH 5 to MnTH 100.

Minnesota Fringe Freeway Segments

- I-694 from I-494 East Junction to I-94 and from MnTH 100 to I-494 West Junction.
- I-494 from I-694 East Junction to MnTH 5 and from MnTH 100 to I-694 West Junction.
- I-394 from MnTH 100 to I-494.
- I-94 from US Highway 61 to Wisconsin Border and from I-494/I-694 West Junction to MnTH 101.
- I-35W from I-35E South Junction to MnTH 62 and from MnTH 36 to I-35E North Junction.
- I-35E from I-35W South Junction to I-94 and from MnTH 36 to I-35W North Junction.
- I-35 from MnTH 50 to I-35W/I-35E South Junction and from I-35W/I-35E North Junction to US Highway 8.

Minnesota Rural Freeway Segments

- I-90 from Wisconsin Border to South Dakota Border.
- I-94 from MnTH 101 to North Dakota Border.
- I-35 from US Highway 8 to Duluth, Minnesota and from MnTH 50 to Iowa Border.

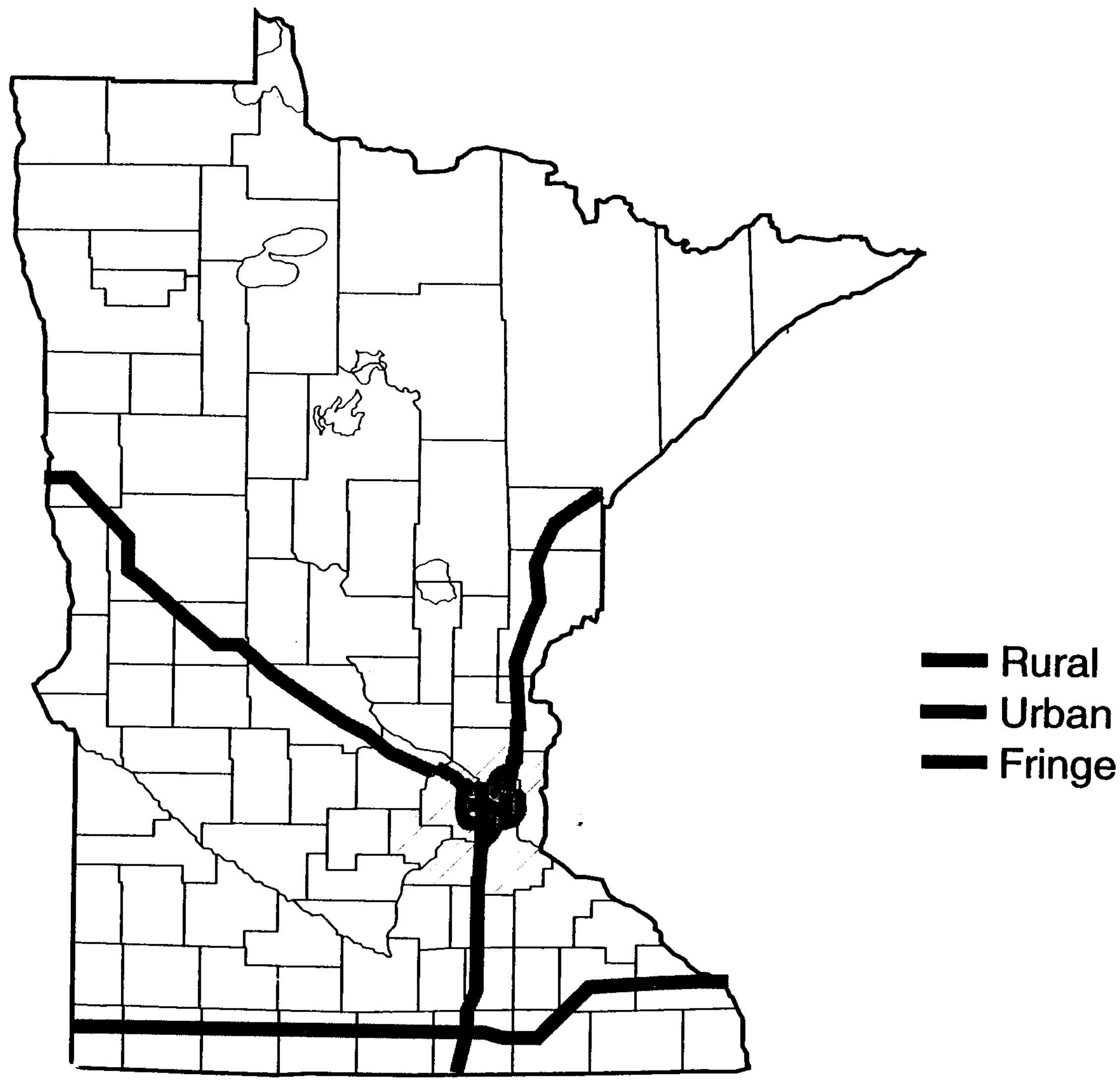


Figure 8. Minnesota rural interstate freeways.

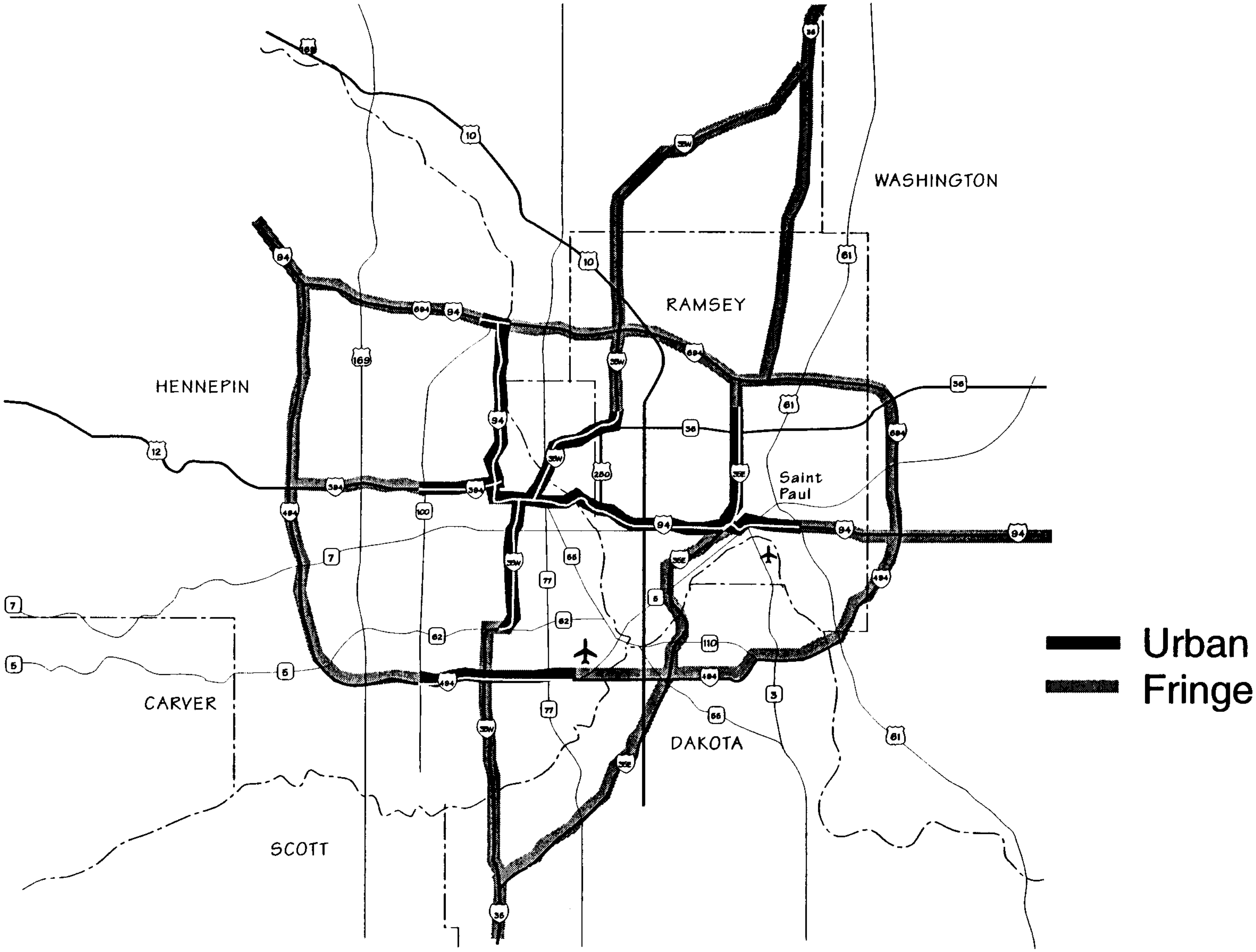


Figure 9. Minnesota urban and fringe interstate freeways.

Data supplied by the Mn/DOT Office of Traffic Engineering indicates that the total interstate freeway mileage in the State of Minnesota is 1,410 km (891 mi). The urban, fringe, and rural components of this mileage are shown in figure 10. The data indicate that 77 percent of the interstate freeway mileage within the State of Minnesota is classified as "rural," 18 percent of the mileage is "fringe" and 5.2 percent of the mileage is "urban."

Technical Issues

A flow chart of the technical issues analyzed for the urban/rural AHS comparison are shown in figure 11. The issues consist of geometric design characteristics such as interchange spacing, lane width and curvature and vehicle characteristics such as vehicle classification, braking, acceleration and deceleration. The following paragraphs summarize the analysis and findings of the technical issues as they relate to actual freeway segments within the State of Minnesota. The current American Association of State Highway and Transportation Officials (AASHTO) guidelines from the *Policy on Geometric Design of Highways and Streets* (the Green Book), 1990 edition, are also provided, where appropriate, for extrapolation purposes to the national level.

Geometric Design Characteristics

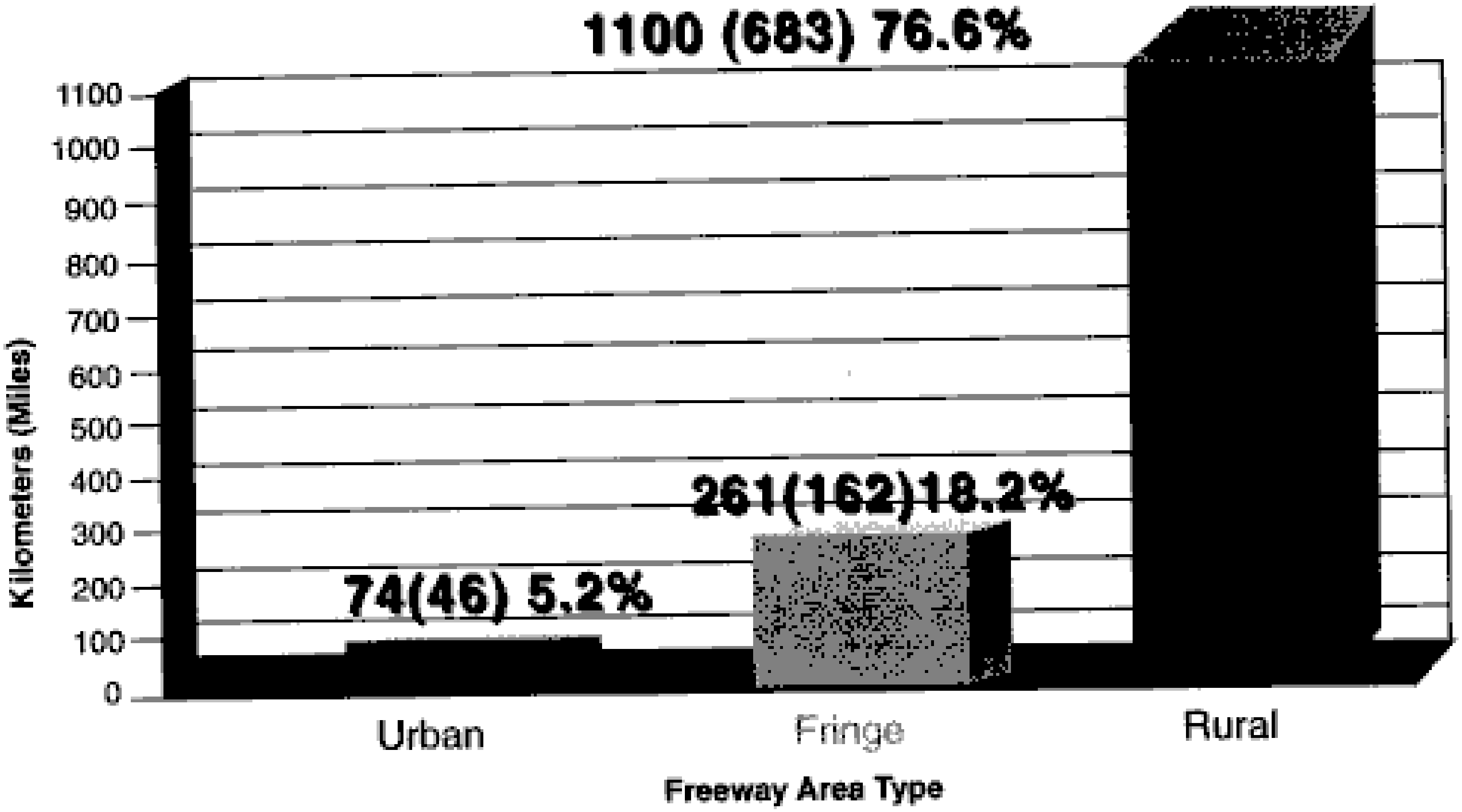
Interchange Spacing

The AASHTO Green Book suggests rules of thumb for minimum interchange spacing of 0.6 km (1 mi) in urban areas and 3.2 km (2 mi) in rural areas. The Green Book does not indicate an interchange spacing difference between land access interchanges and system interchanges, which provide freeway to freeway connections. The observed interstate freeway interchange spacing within the State of Minnesota is shown in figure 6 and described below.

Land access interchanges along urban interstate freeways are typically spaced between 0.8 km (1/2 mi) and 1.6 km (1 mi) apart and system interchanges are usually spaced 3.2 km (2 mi) to 4.8 km (3 mi) apart, depending upon development and population densities.

Land access interchanges along fringe freeways are usually spaced 1.2 km (3/4 mi) to 3.2 km (2 mi) apart and system interchanges are typically spaced 4.8 km (3 mi) apart.

Land access interchanges along rural interstate freeways are typically spaced between 3.2 km (2 mi) and 8 km (5 mi) apart. System interchange spacing along rural freeways is variable as it is dependent upon the intersection locations with other major roadways.



Source: Mn/DOT Metro Division: Office of Traffic Engineering

Figure 10. Minnesota interstate freeway lengths.

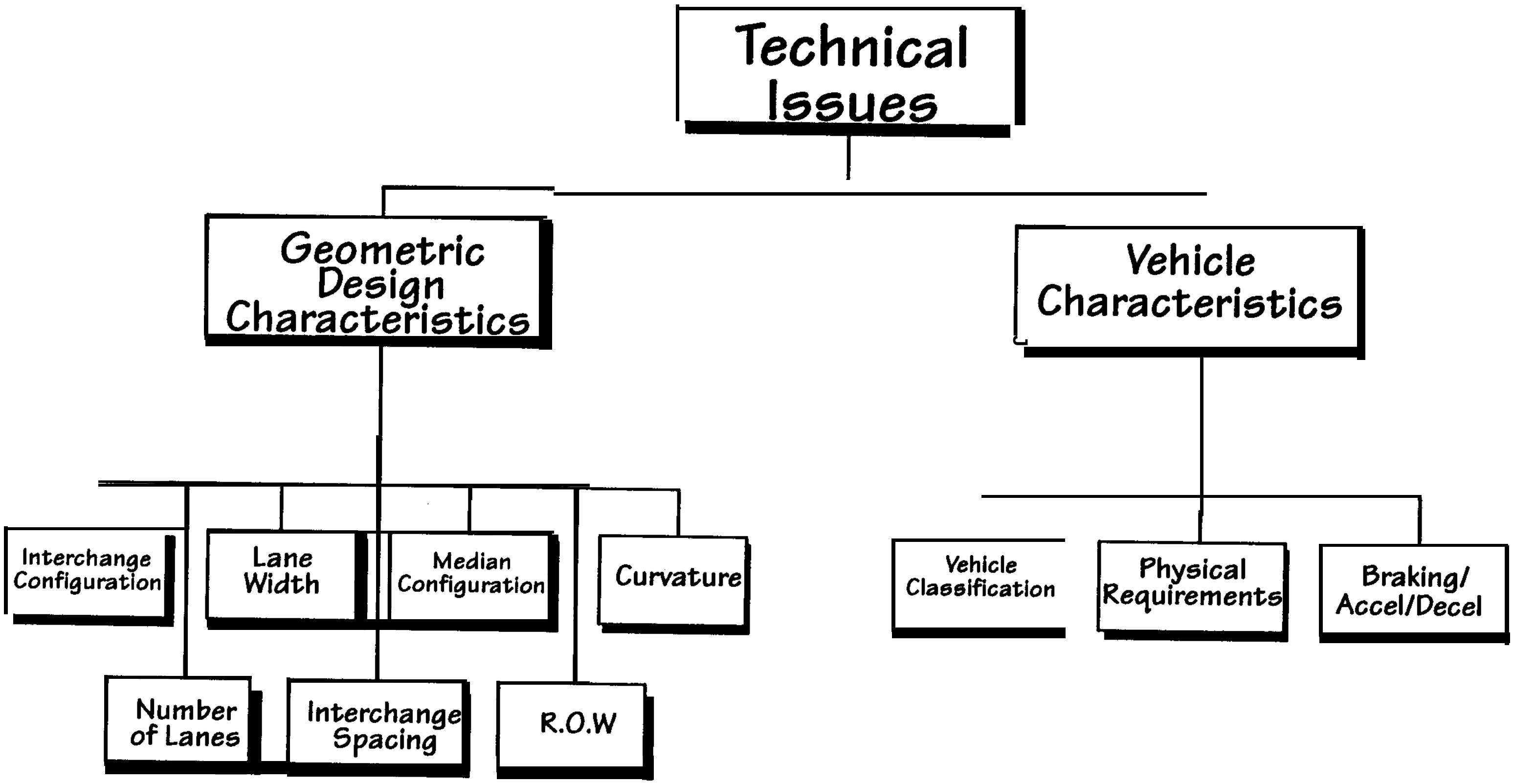


Figure 11. Task A technical issues.

Interchange Configuration

The AASHTO Green Book indicates that the selection of the proper interchange configuration is dependent upon right-of-way availability, capacity, weaving, lane balance/route continuity, cost, etc. Schematic examples of typical interchange types are shown in figures 12, 13, and 14. Scaled designs of five of the most typical interchange configurations are illustrated in figures 15 through 19.

The typical configurations for system interchanges within the State of Minnesota consist of cloverleaf and directional type interchanges in urban areas, cloverleaf interchanges with collector/distributor road connections in fringe areas and cloverleaf interchanges in rural areas.

Land access interchange configurations within the State of Minnesota consist mainly of full-diamond-type interchanges in urban, fringe and rural areas. Some other interchange types (half-diamond, folded-diamond, and partial cloverleaf) are used in some urban and fringe areas where there is short interchange spacing or right-of-way constraints.

Number of Lanes/Lane Width

The AASHTO Green Book indicates that freeways typically provide from two to eight lanes of traffic flow per direction and that all through traffic lanes should be 3.6 m (12 ft) wide.

Within the state of Minnesota, the urban freeways provide from two to five lanes per direction, the fringe freeway segments provide from two to four lanes per direction and the rural freeway segments provide two lanes per direction. All interstate freeway through traffic lanes are 3.6 m (12 ft) in width.

Shoulder Width

The AASHTO Green Book recommends left shoulder widths of 1.2 to 2.4 m (4 to 8 ft) for four lane freeways and 3 to 3.6 m (10 to 12 ft) for freeways of six or more lanes and right shoulder widths of 3 to 3.6 m (10 to 12 ft) for all freeways. The Green Book also states that where the truck volume exceeds 250 design hour volume (DHV), the greater shoulder widths should be provided.

Median Configuration

The AASHTO Green Book states that the minimum median width for a four lane urban freeway is 3 m (ten ft, two 4-ft shoulders and a 2-ft median barrier), and that the minimum for a six or more lane urban freeway is 8 m (26 ft, two 12-ft shoulders and a 2-ft median barrier). The Green Book also states that the minimum median width for a

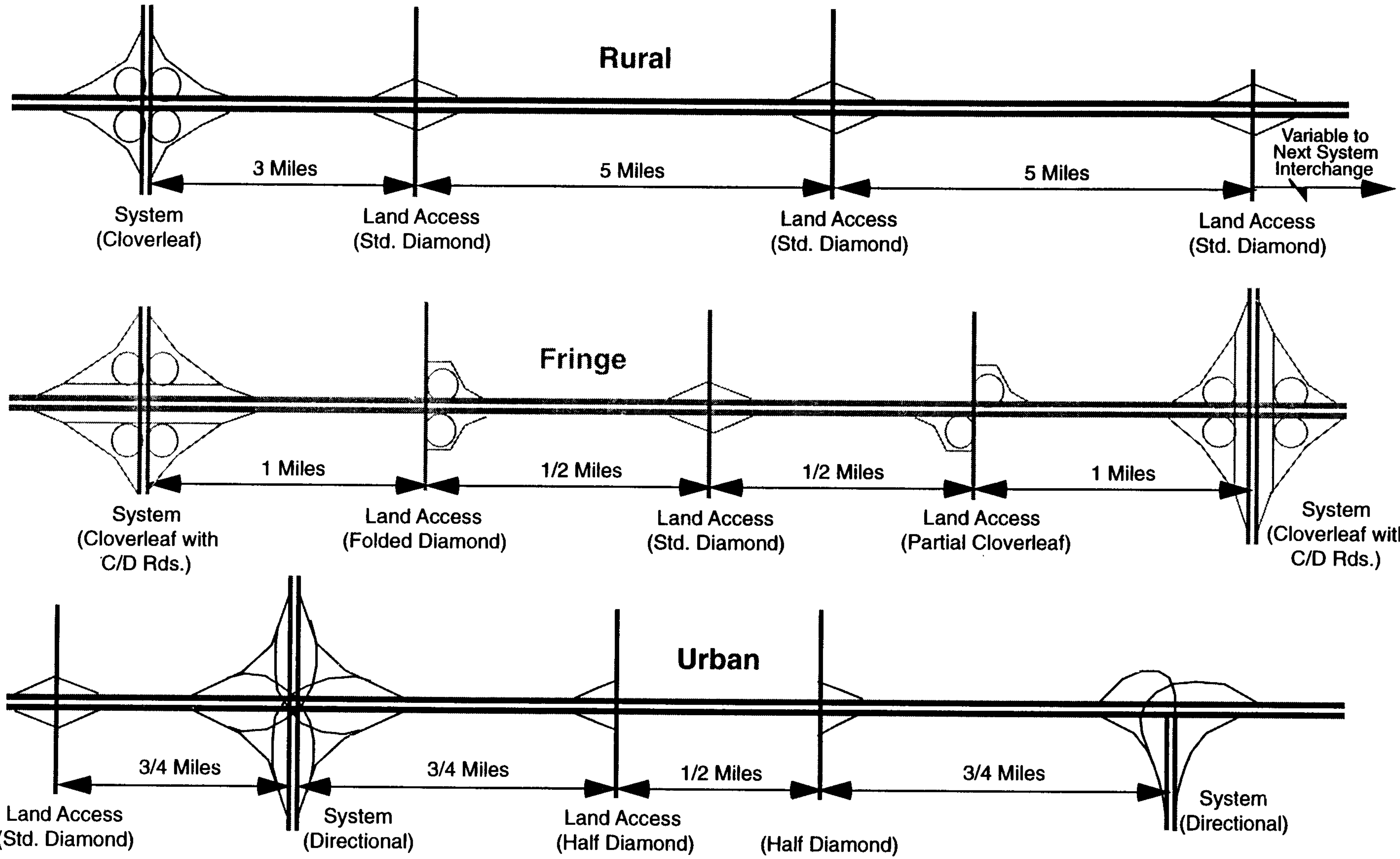


Figure 12. Typical freeway interchange configurations and spacing.

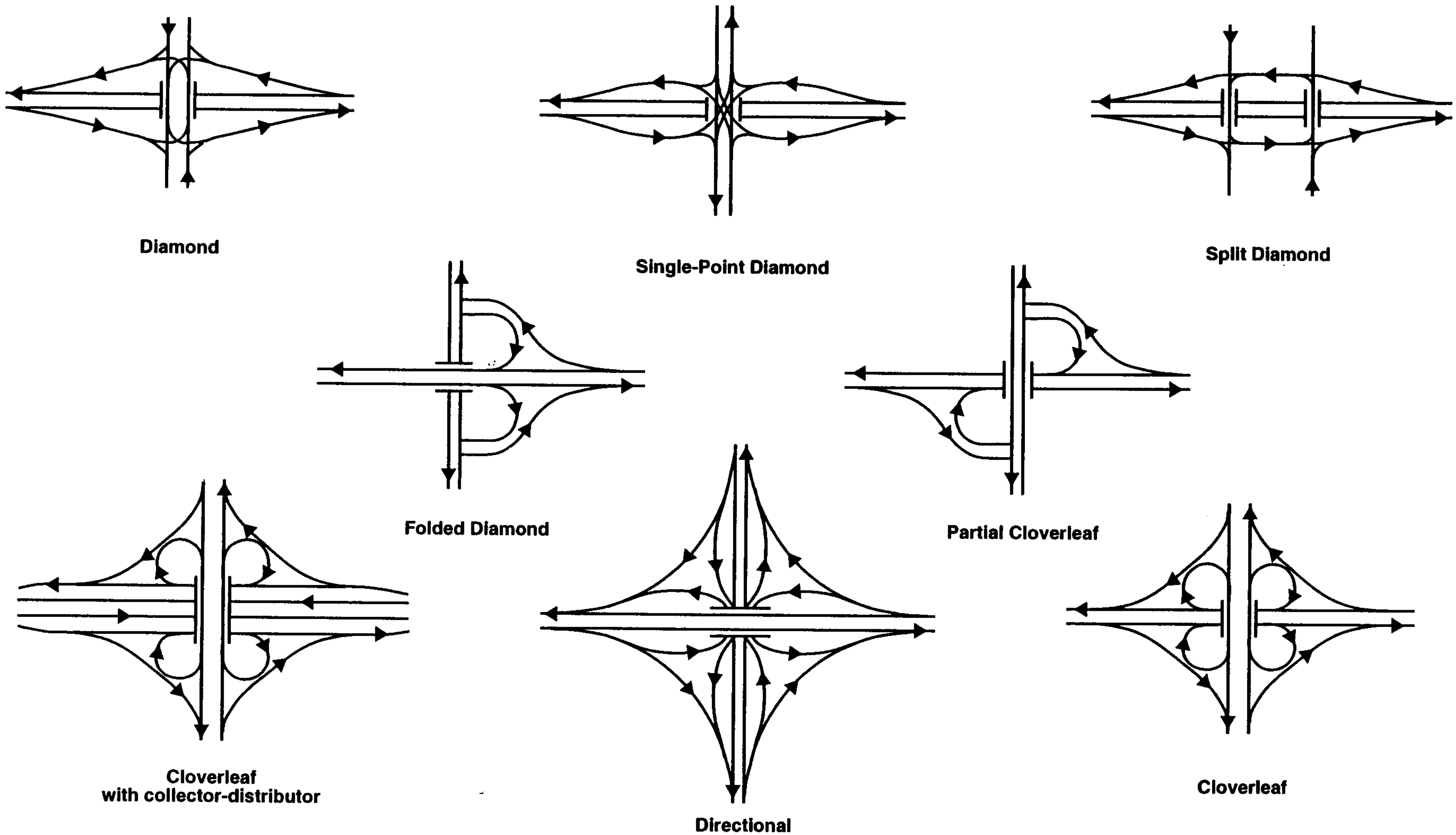


Figure 13. Typical freeway interchanges.

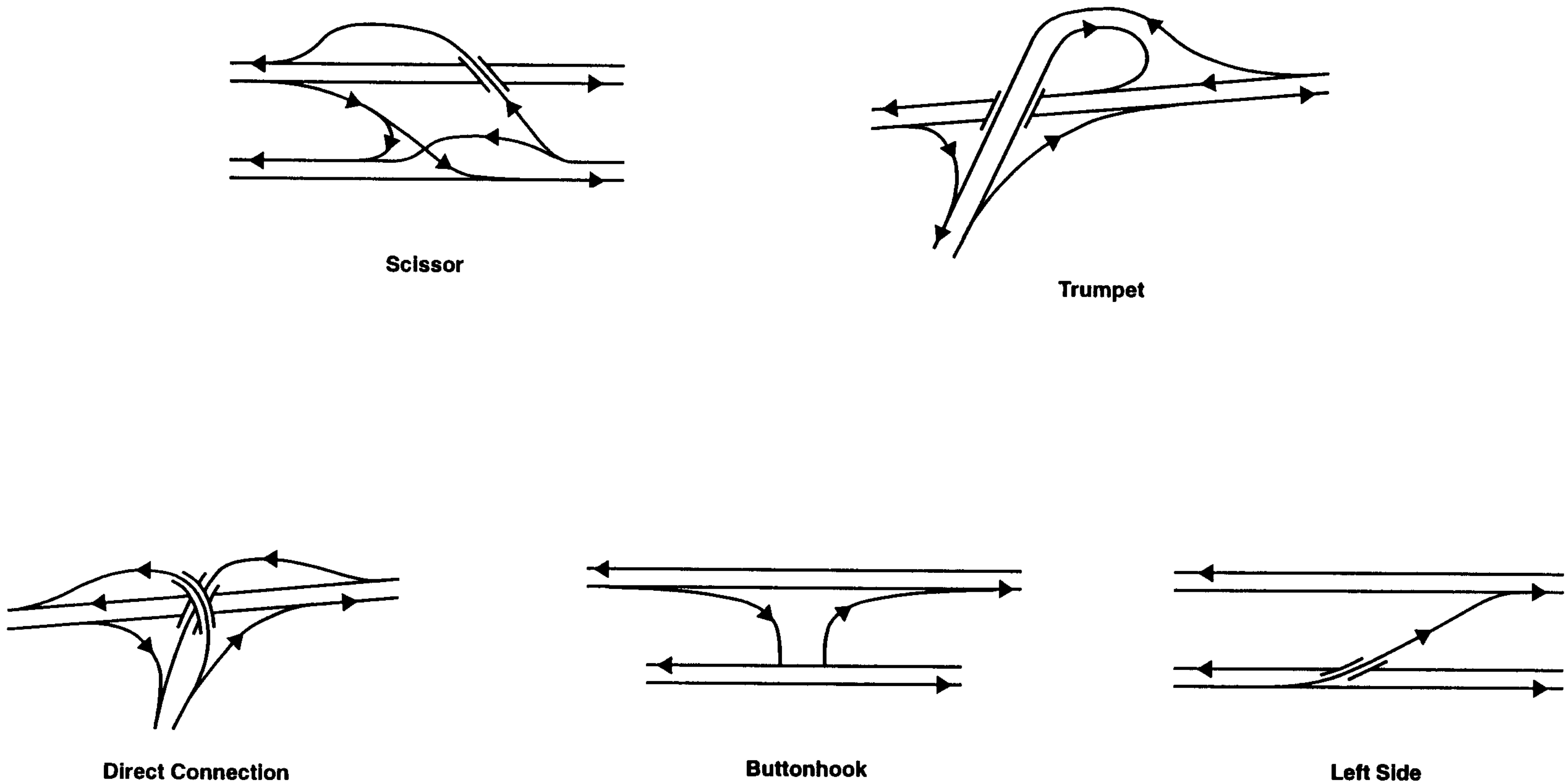


Figure 14. Typical freeway interchanges.

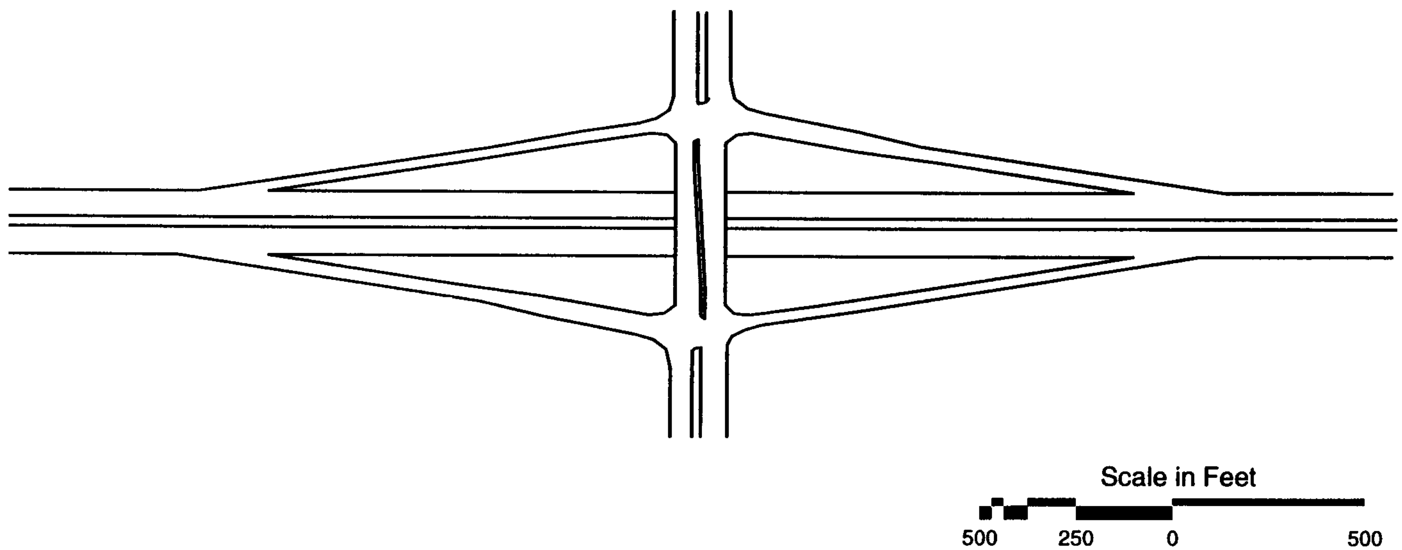


Figure 15. Typical diamond interchange.

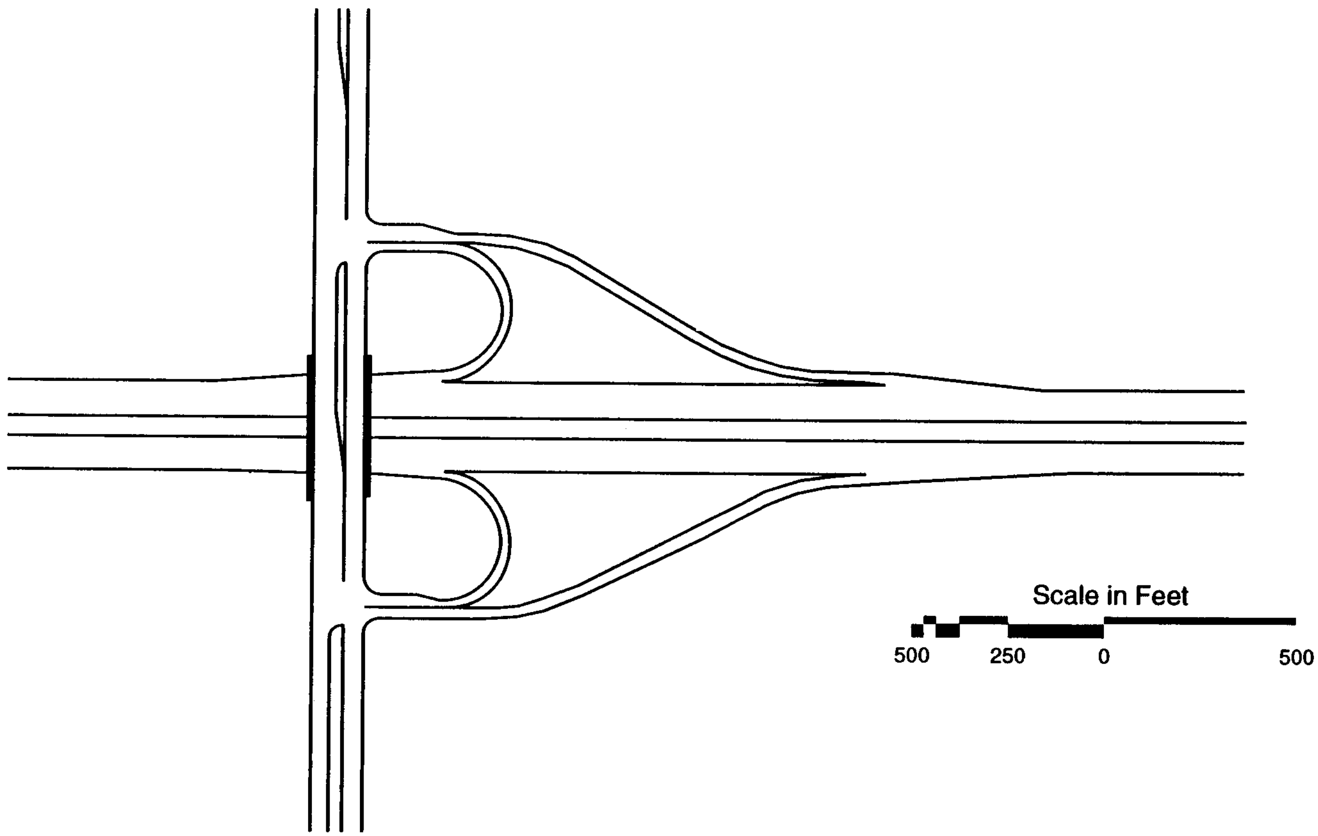


Figure 16. Typical folded-diamond interchange.

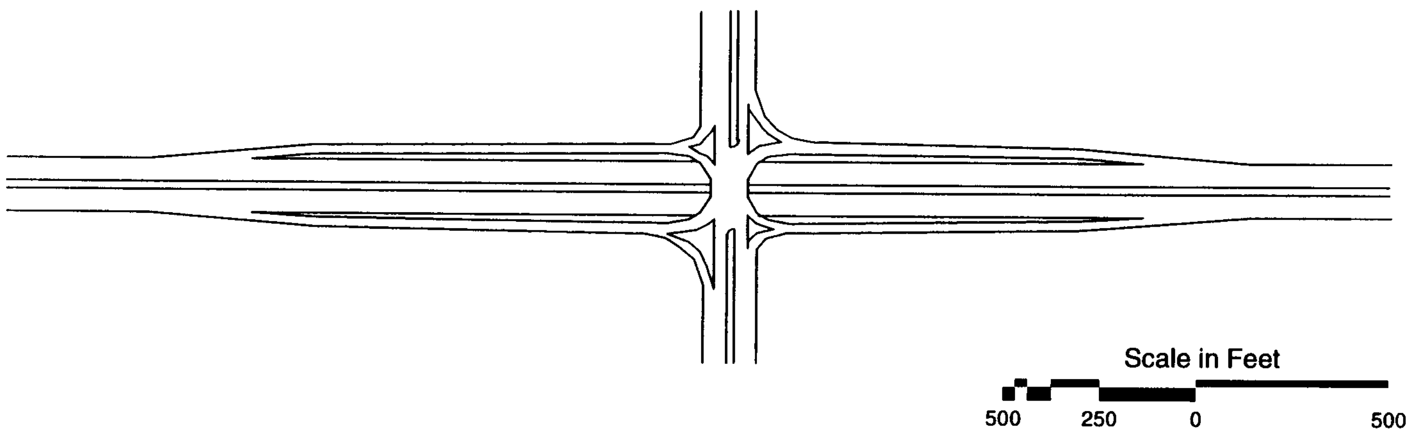


Figure 17. Typical single-point diamond interchange.

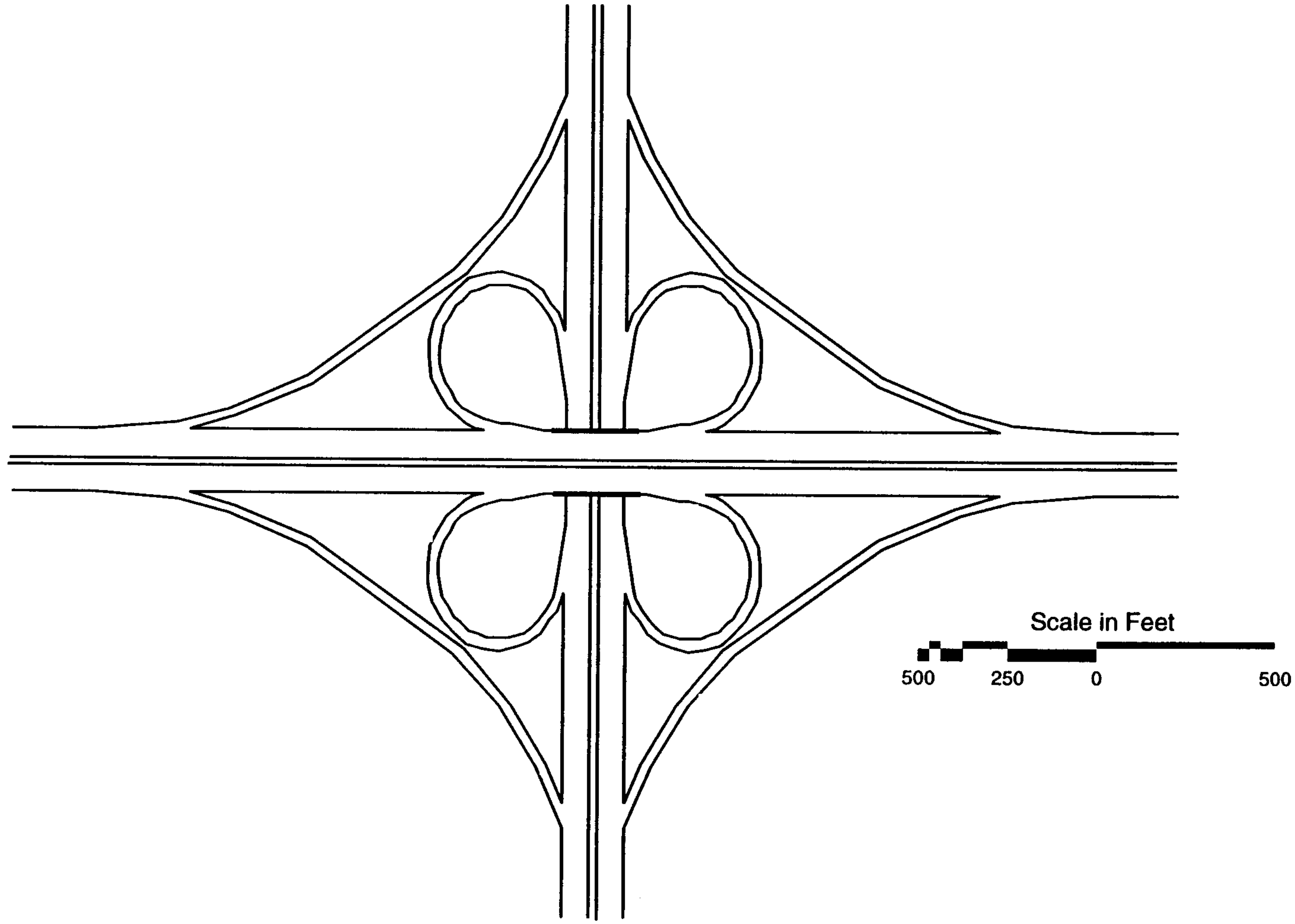


Figure 18. Typical cloverleaf interchange.

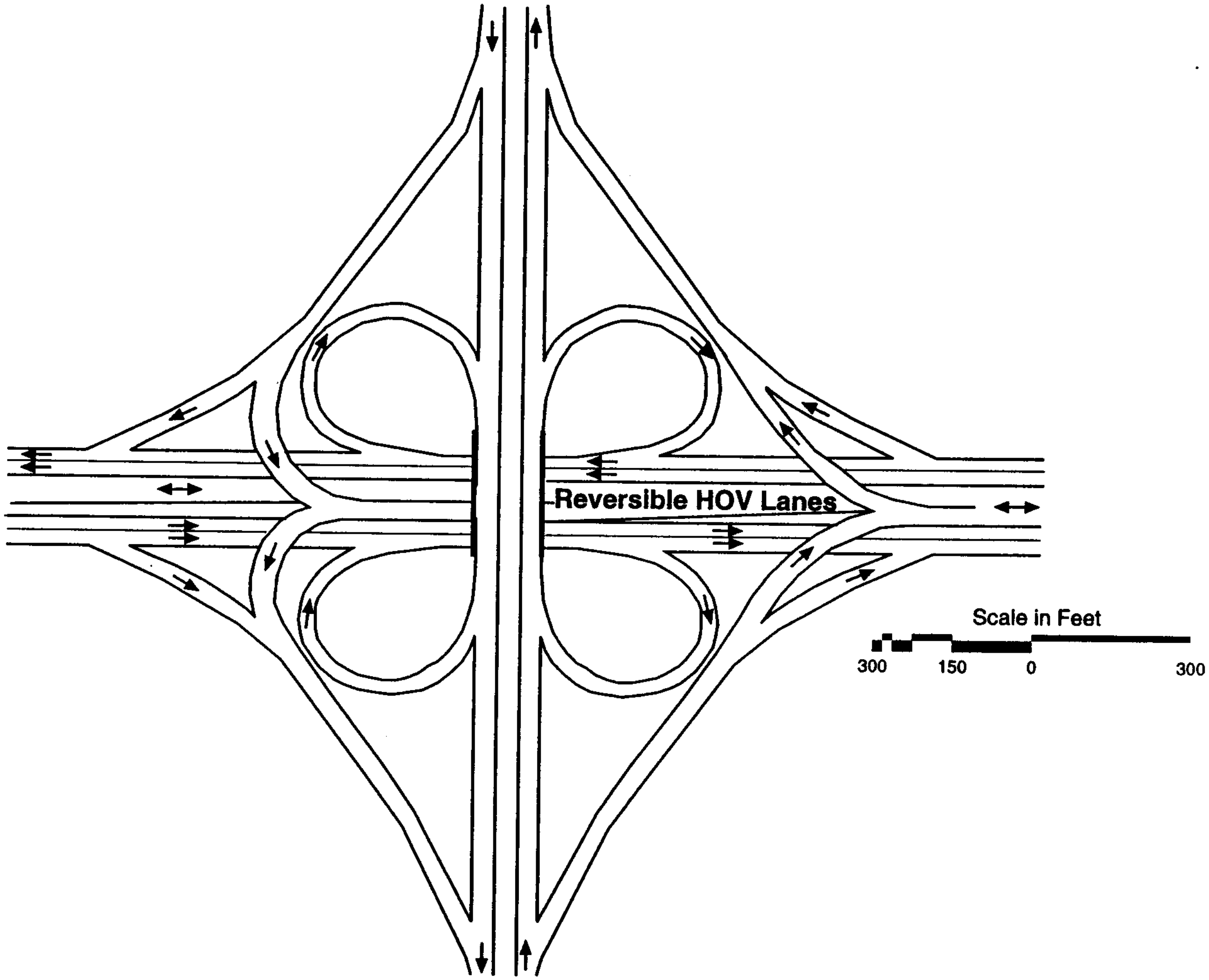


Figure 19. Typical cloverleaf interchange with collector/distributor roads and HOV connections.

rural freeway is approximately 18 m (60 ft, which includes 6 to 10-ft shoulders, 6:1 foreslopes and a 3-ft ditch). The desirable rural median width is roughly 30 m (100 ft). Illustrations of these AASHTO guidelines are shown in figure 20.

Right-Of-Way Widths

The right-of-way widths along freeway segments are dependent upon the roadway cross-section and slopes, the adjacent topography and development and the availability and cost of additional right-of-way. In general, rural freeways usually have greater right-of-way widths than urban and fringe freeways. Typical interstate freeway right-of-way widths vary between 60 and 120 m (200 and 400 ft). Examples of urban, fringe and rural right-of-way widths with a level roadway are shown in figure 20. The relative impacts of median configuration, slopes and cross-section (with or without frontage roads) on right-of-way width can be gauged from figure 20.

Design Speed/Curvature/Grade

The AASHTO Green Book recommends minimum and desirable freeway design speeds of 80 and 110 km/h (50 and 70 mph), respectively, and maximum horizontal curvatures of 635 m and 410 m radii (2,084 and 1,350 ft) for rural and urban freeways, respectively. The Green Book also suggests maximum freeway gradients of 3 to 5 percent, with 6 percent allowed in mountainous areas.

Vehicle Characteristics

Vehicle Classification

The classification of vehicles by type is used to help design roadway pavements and to determine appropriate shoulder widths. The Mn/DOT classification system is based on the ten vehicle types documented in the Pavement Design Chapter of the *Mn/DOT Road Design Manual*. These vehicle types are shown in figure 21.

Vehicle classification percentages for typical urban, fringe and rural freeway segments are shown in table 5. The data indicate that the percentage of automobiles at these three locations is high, ranging from almost 94 percent (rural) to 97 percent (fringe). Classification data from all other freeway segments within the State of Minnesota indicate that the commercial percentages vary from roughly 4 to 8 percent on urban freeways, 2 to 13 percent on fringe freeways and 6 to 23 percent on rural freeways.

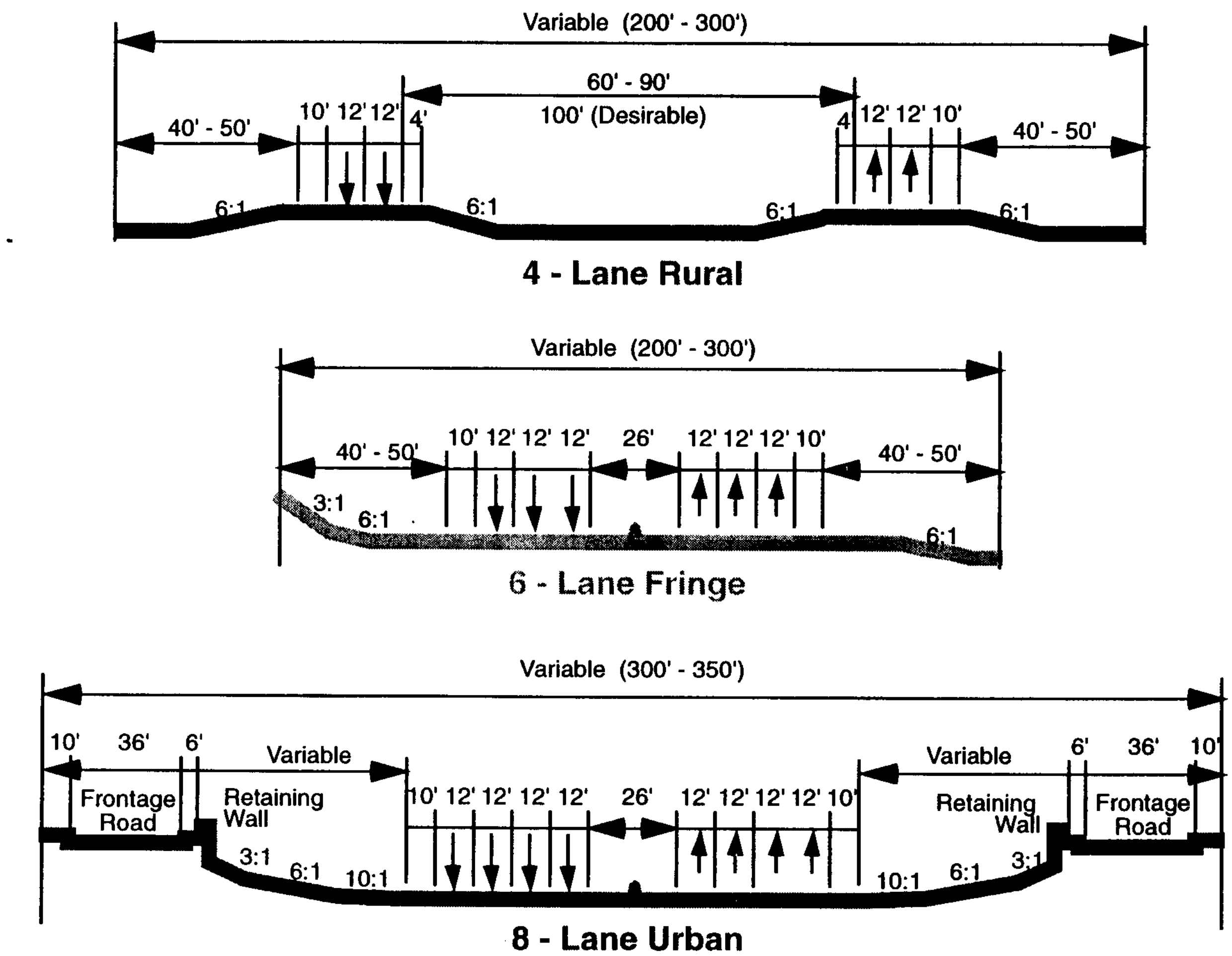
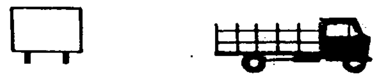


Figure 20. Typical freeway cross section.

Vehicle Type Number	Illustrated Example	Vehicle Description
1		**Passenger Cars**
2		**Panel and Pickups (Under 1 ton)**
3		**Single Unit- 2 axle, 4-tire**
4		**Single Unit- 2 axle, 6-tire**
5		**Single Unit- 3 axle and 4 axle**
6		**Tractor Semitrailer Combination-3 axle**
7		**Tractor Semitrailer Combination-4 axle**
8		**Tractor Semitrailer Combination-5 axle**
9		**Tractor Semitrailer Combination-6 axle**
10		**Trucks with Trailers**

**Source: Mn/DOT Road Design Manual.*

Figure 21. Vehicle types.

Table 5. Vehicle distribution percentages by freeway area type.

Vehicle Type	Description	Freeway Area Type		
		Rural (I-35 North of Wyoming - 1991)	Fringe (I-394 - 1992)	Urban (I-94 - 1992)
1&2	Passenger Cars, Panels and Pickups (under 1 ton)	94.60	96.36	95.47
3&4	Single Unit - 2 axle	1.23	1.74	1.63
5	Single Unit - 3 axle & 4 axle	0.33	0.46	0.46
6	Tractor Semitrailer Combination - 3 axle	0.10	0.09	0.13
7	Tractor Semitrailer Combination - 4 axle	0.16	0.19	0.11
8	Tractor Semitrailer Combination - 5 axle	3.16	0.74	1.50
9	Tractor Semitrailer Combination - 6 axle	0.09	0.21	0.15
10	Trucks with Trailers	0.12	0.01	0.04
-	Buses	0.11	0.20	0.51
-	Twin Trailers	0.10	0.00	0.00

Vehicle Braking/Acceleration/Deceleration

The AASHTO Green Book provides estimates of automobile braking distances at various speeds (table 6). The values shown in table 6 are for wet pavements on a level roadway. An uphill grade would decrease these values, while a downhill grade would increase the values. Note that these values are for braking distance only, they do not include distance for perception/reaction.

Typical automobile acceleration and deceleration rates, distances and times are shown in tables 7 and 8, respectively. These data were obtained from the *Transportation and Traffic Engineering Handbook*, published by the Institute of Transportation Engineers.

Operational Issues: A flow chart of the operational issues analyzed in the urban/rural AHS comparison is shown in figure 22. The issues include traffic flow characteristics, accident characteristics and trip characteristics. The following paragraphs summarize the analysis and findings of the operational issues relative to actual interstate freeway segments within the State of Minnesota.

Traffic Flow Characteristics

Vehicle Kilometers (Miles) of Travel

The daily vehicle km of travel (VKMT) on the urban, fringe and rural interstate freeway segments within the State of Minnesota were obtained from the Mn/DOT Office of Traffic Engineering. The data indicate that the urban VKMT is approximately 7,952,000 km (4,970,000 mi) per day, the fringe VKMT is roughly 13,744,000 km (8,590,000 mi) per day and the rural VKMT is almost 12,576,000 km (7,860,000 mi) per day.

Average Daily Traffic

The urban, fringe and rural average daily traffic (ADT) volume ranges for the interstate freeway segments within the State of Minnesota are shown in figure 23. The data indicate that the ADTs vary from 82,000 vehicles per day (vpd) to 220,000 vpd on urban segments, from 29,000 vpd to 84,000 vpd on fringe segments and from 7,000 vpd to 15,000 vpd on rural segments. These traffic volumes were obtained from the Mn/DOT *1990 Traffic Flow Maps*.

The weighted average ADTs for the freeway segments within the State of Minnesota are 108,000 vpd for urban segments, 53,000 vpd for fringe segments and 11,500 vpd for rural segments. This data was obtained from the Mn/DOT Office of Traffic Engineering.

Table 6. Typical automobile braking characteristics.

Assumed Speed for Condition (mph)	Wet Coefficient of Friction (f)	Braking Distance on Level (feet)*
20-20	0.40	33.3-33.3
24-25	0.38	50.5-54.8
28-30	0.35	74.7-85.7
32-35	0.34	100.4-120.1
36-40	0.32	135.0-166.7
40-45	0.31	172.0-217.7
44-50	0.30	215.1-277.8
48-55	0.30	256.0-336.1
52-60	0.29	310.8-413.8
55-65	0.29	347.7-485.6
58-70	0.28	400.5-583.3

* AASHTO- Geometric Design of Highways and Streets

Table 7. Typical automobile acceleration characteristics.

Speed Range (MPH)	Accel Rate (MPH/Sec)	Time to Accel (Sec)	Distance Traveled (Miles)	Cumulative Values From 0 MPH	
				Time	*Dist*
0-5	3.3	1.5	.001	1.5	.001
5-10	3.3	1.5	.003	3.0	.004
10-15	3.3	1.5	.005	4.5	.009
15-20	3.3	1.5	.007	6.1	.017
20-25	3.3	1.5	.009	7.6	.026
25-30	3.3	1.5	.012	9.1	.038
30-35	3.3	1.5	.014	10.6	.052
35-40	3.3	1.5	.016	12.1	.067
40-45	2.6	1.9	.023	14.0	.090
45-50	2.6	1.9	.025	16.0	.115
50-55	2.0	2.5	.036	18.4	.152

Source: Transportation and Traffic Engineering Handbook, Institute of Transportation Engineers, 2nd Edition.

Table 8. Typical automobile deceleration characteristics.

Speed Range (MPH)	Accel Rate (MPH/Sec)	Time to Decel (Sec)	Distance Traveled (Miles)	Cumulative Values From 0 MPH	
				Time	*Dist*
5-0	5.3	0.9	.001	0.9	.001
10-5	5.3	0.9	.002	1.9	.003
15-10	5.3	0.9	.003	2.8	.006
20-15	4.6	1.1	.005	3.9	.011
25-20	4.6	1.1	.007	5.0	.018
30-25	4.6	1.1	.008	6.1	.026
35-30	3.3	1.5	.014	7.6	.040
40-35	3.3	1.5	.016	9.1	.056
45-40	3.3	1.5	.018	10.6	.074
50-45	3.3	1.5	.020	12.2	.094
55-50	3.3	1.5	.022	13.7	.116

Source: Transportation and Traffic Engineering Handbook, Institute of Transportation Engineers, 2nd Edition.

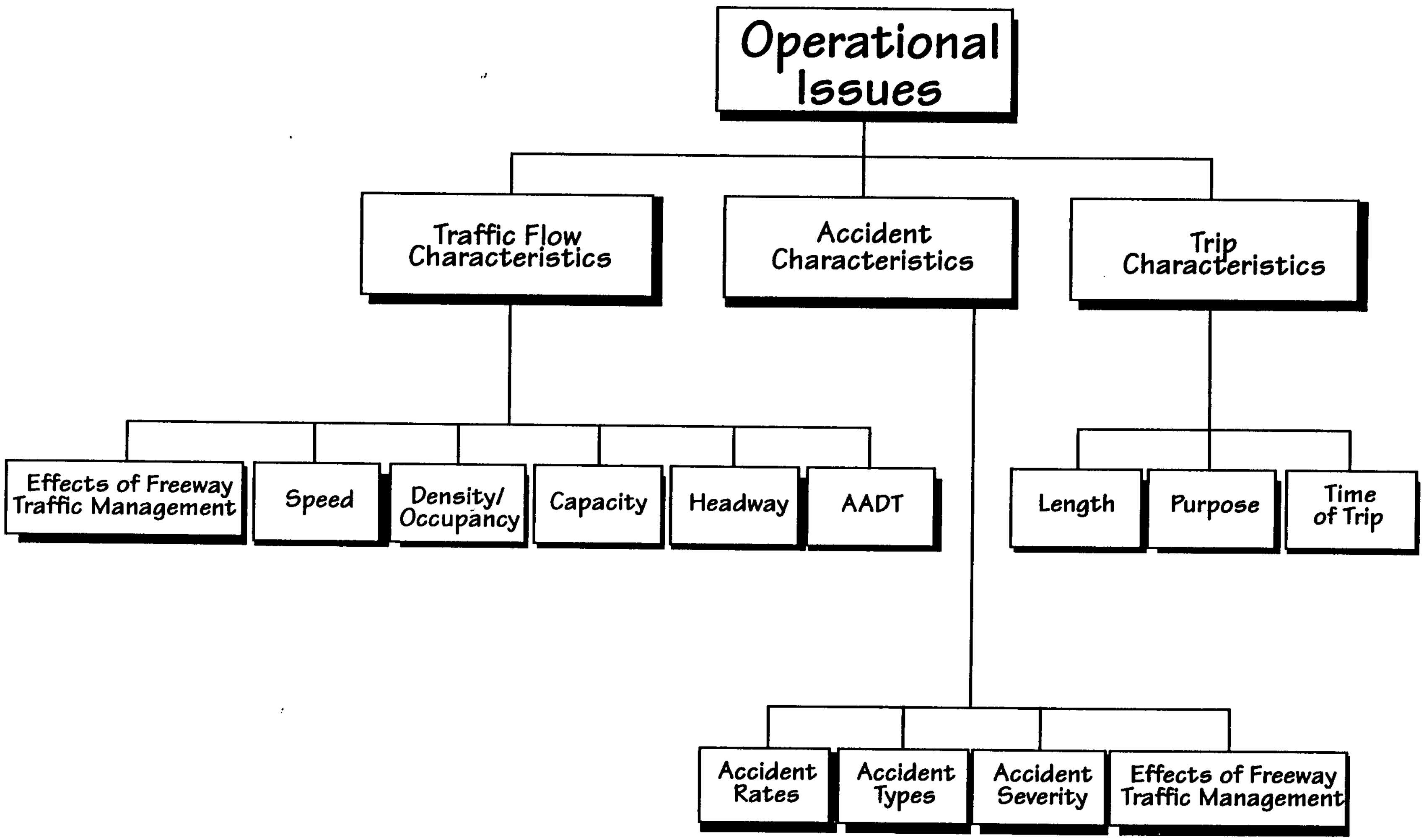


Figure 22. Task A operational issues.

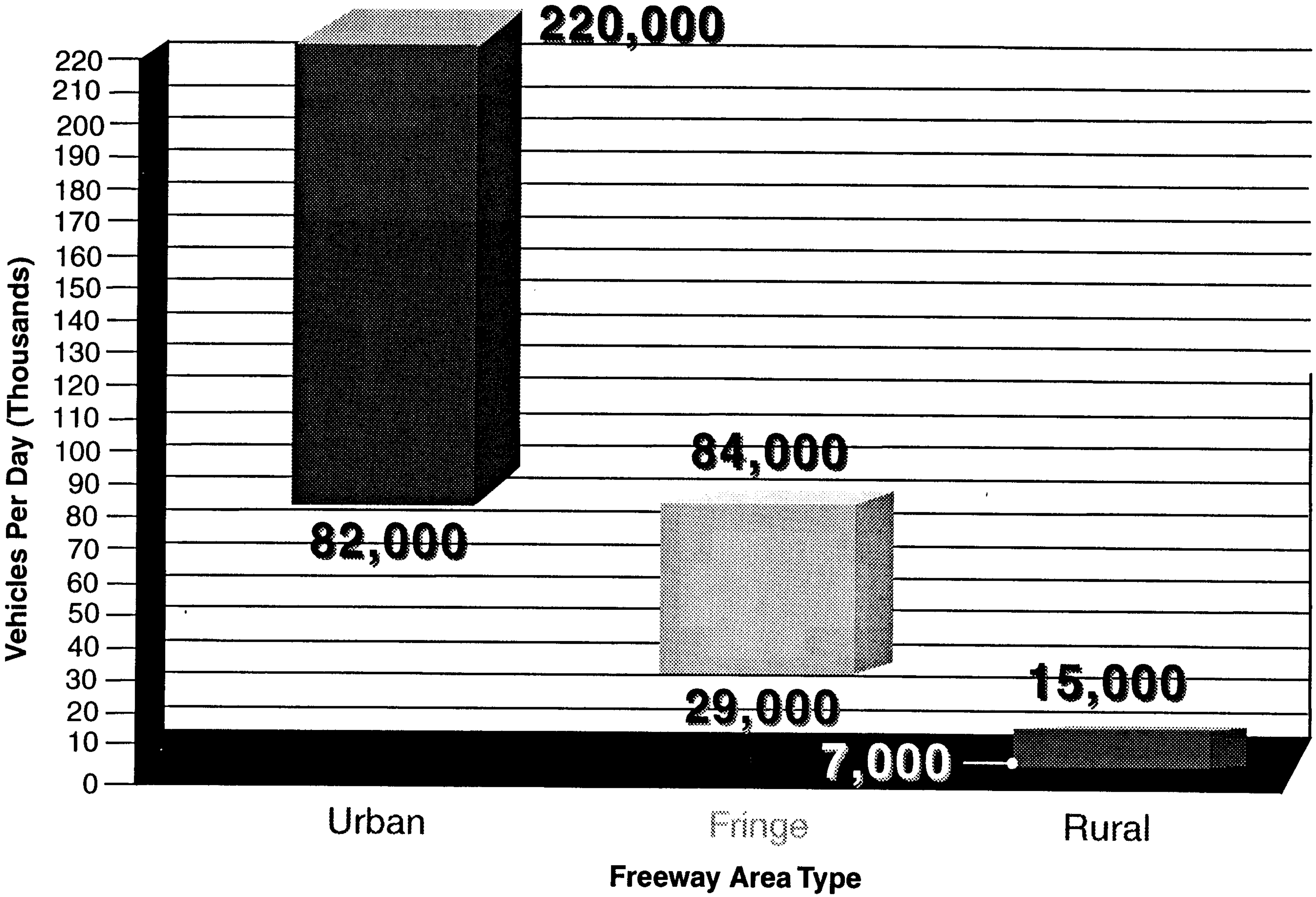


Figure 23. Minnesota freeway-AADT by area type.

Peak Hour Capacity

The urban, fringe and rural peak hour lane capacities for the interstate freeway segments within the State of Minnesota are shown in figure 24. The urban capacity of 2,400 vehicles per hour per lane (vphpl) is a typical PM peak hour value for the section of I-35W between downtown Minneapolis and MnTH 62. This data was obtained from the Mn/DOT Freeway Operations Section.

The fringe freeway capacity of 2,000 vphpl is an assumed value obtained directly from the *1985 Highway Capacity Manual*. However, data indicate that some fringe sections of I-35W, I-494 and I-694 have accommodated 2,100 to 2,200 vphpl.

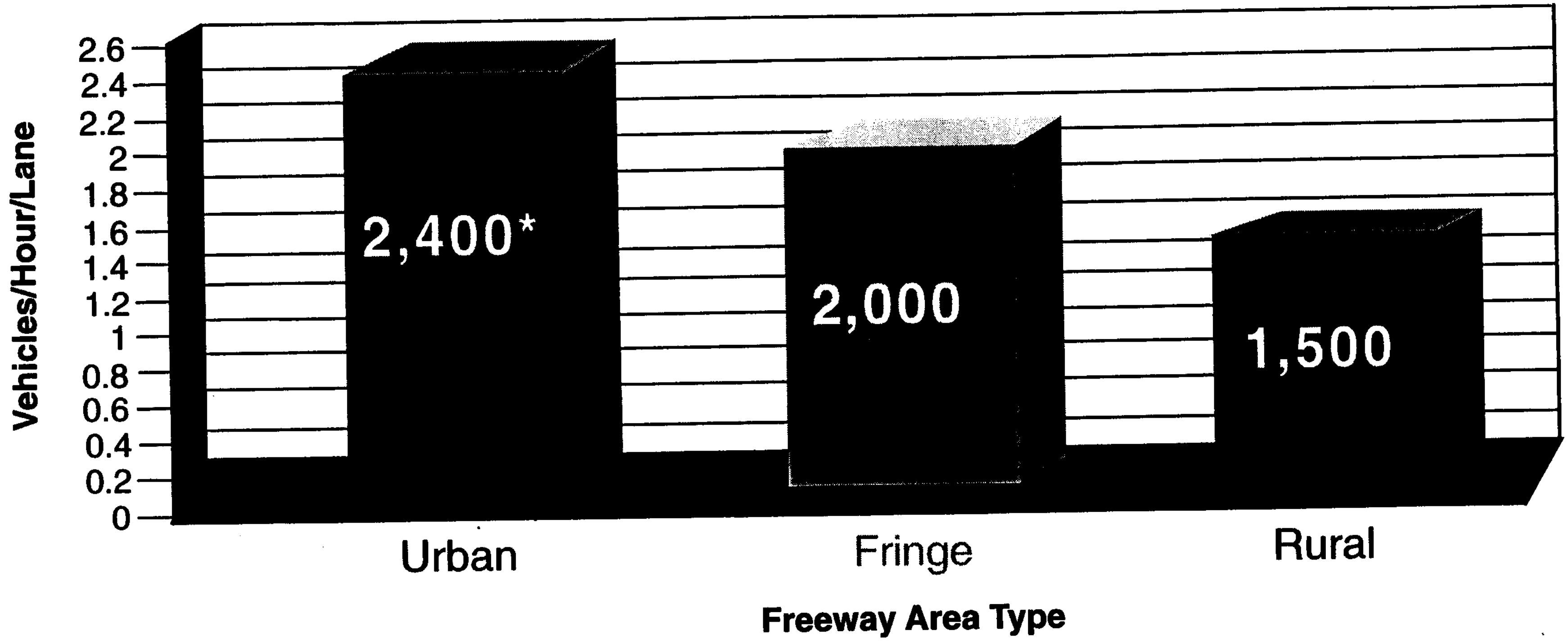
It should be noted that all of the segments of urban and fringe freeways with capacities in excess of 2,000 vphpl are under the control of Mn/DOT's Traffic Management Center and the increased capacity is the result of implementing advanced freeway traffic management strategies.

The *1985 Highway Capacity Manual* (HCM) indicates that the freeway capacity in rural areas is less than those in urban or fringe areas. The HCM Freeway Operations Procedures document an adjustment factor be used to account for the character of the traffic stream. The analysis suggests values for the adjustment factor ranging from 0.75 to 0.90. Based on observations of rural freeway traffic flow, the conservative 0.75 adjustment factor was selected. This results in a rural freeway hourly capacity estimate of 1,500 vphpl (2000 x 0.75). This rural freeway hourly capacity appears reasonable since the rural section of I-35 between the Minneapolis/St. Paul Metro Area and the City of Duluth carried slightly over 1,500 vphpl during twelve hours in 1992.

Typical Vehicle Headways

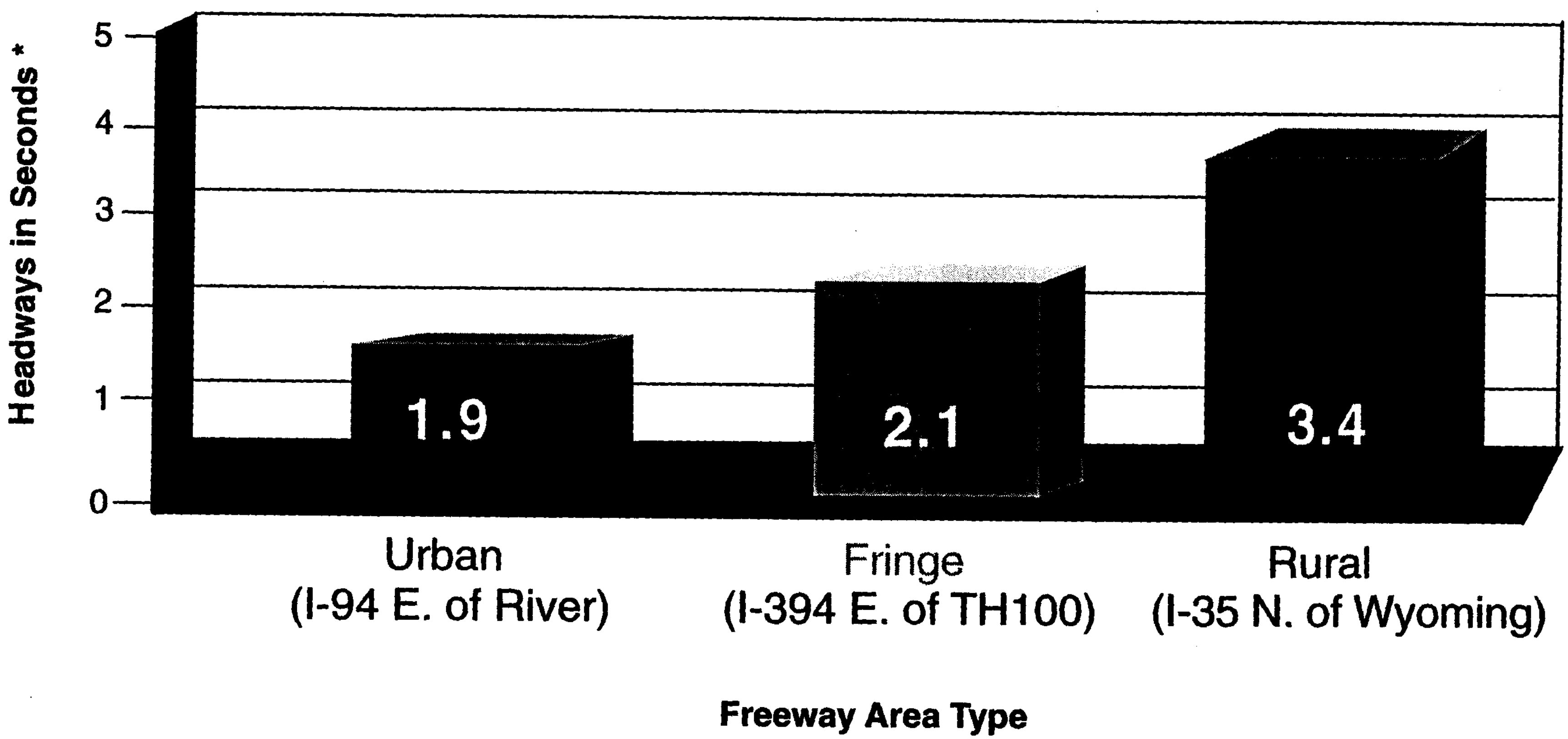
The average vehicle headways on the freeway segments within the State of Minnesota were estimated by using the 100th highest hourly volume at three typical urban, fringe and rural locations. The 100th highest hourly volume was chosen because it negates the effects of using the highest hours of the year and still results in a fairly conservative estimate of vehicle headways. The average vehicle headways during the 100th highest hour are shown in figure 25. The data indicate that the average 100th hour headways are 1.9 seconds/vehicle for urban freeways, 2.1 seconds/vehicle for fringe freeways and 3.4 seconds/vehicle for rural freeways.

If the peak hour volumes noted above are used to determine peak hour headways, the resulting peak hour (i.e., highest hour of the year) headways would be
1.5 seconds/vehicle for urban freeways, 1.8 seconds/vehicle for fringe freeways and
2.4 seconds/vehicle for rural freeways.



* On I-35W Between downtown Minneapolis and TH62
Source: Mn/DOT Freeway Operations Section and 1985 Highway Capacity Manual

Figure 24. Hourly freeway capacity by area type.



* During 100th Highest Hour

Figure 25. Average freeway headways by area type.

Travel Speed

The current interstate freeway speed limits are 55 mph in urban and fringe areas and 65 mph in rural areas. The observed average travel speeds on the interstate freeway segments within the State of Minnesota are shown in figure 26. These data were obtained from the Mn/DOT Office of Traffic Engineering and are the result of State Patrol observations to determine the State of Minnesota's compliance with the Federal speed limits. The data indicates that the average daily travel speeds along Minnesota Freeways are 58 mph in urban and fringe areas and 68 mph in rural areas.

The contrasting travel speeds during the 100th highest hour of the year are 31 mph along urban freeway segments, 40 mph along fringe freeway segments and roughly 55 mph along rural freeway segments (figure 27). These values were determined by using the 100th highest hourly volumes at three urban, fringe and rural locations and the Freeway Operations Procedures outlined in the *1985 HCM*.

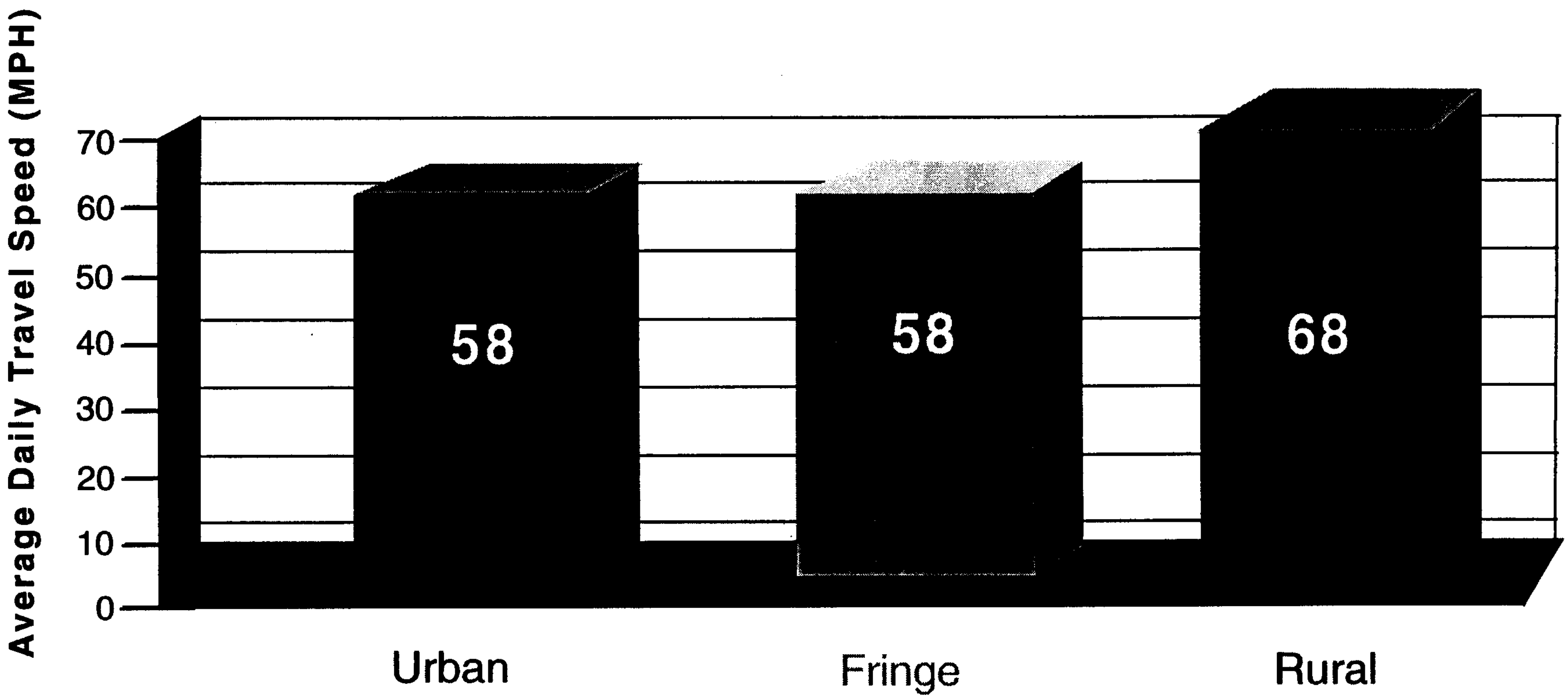
Average Vehicle Occupancy

The average vehicle occupancies on Minnesota freeway segments was determined by using the appropriate data from the Minneapolis/St. Paul Metropolitan Council *1991 Travel Behavior Inventory*. The data indicated that the average vehicle occupancy was 1.23 persons per vehicle along urban freeways, 1.34 persons per vehicle along fringe freeways and 1.43 persons per vehicle along rural freeways (figure 28).

Peak Hour Percent

The relationship between annual peak hours of traffic demand and annual average daily traffic (AADT) by area type is shown in figure 29. This relationship is used by highway engineers to determine the design hour volume (DHV) for highway design purposes. Figure 29 illustrates the relationship for three typical urban, fringe and rural freeway segments within the State of Minnesota.

The data indicate that the rural freeway exhibits much greater peaking characteristics than either the urban or fringe freeway, with the highest hour being roughly 26 percent of the AADT and the 1000th highest hour being nearly 9 percent of the AADT. Highway designers typically design for the 30th highest hour when designing rural freeways. However, since urban and fringe roadways do not show much disparity between the highest hour and the 1000th hour or beyond, designers typically use the peak hour or a value close to the peak hour for design purposes.



Source: Mn/DOT Traffic Engineering

Figure 26. Average freeway daily travel speeds by area type.

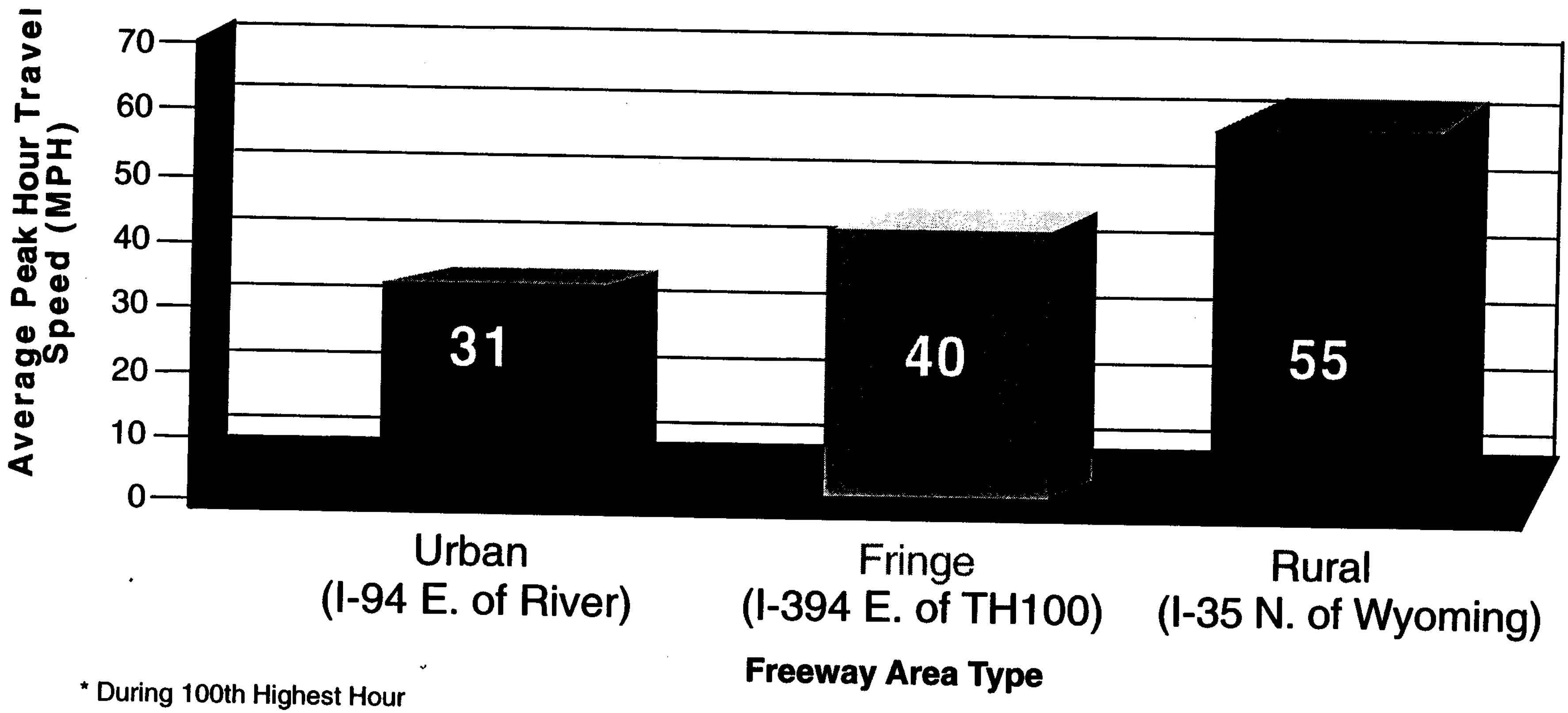
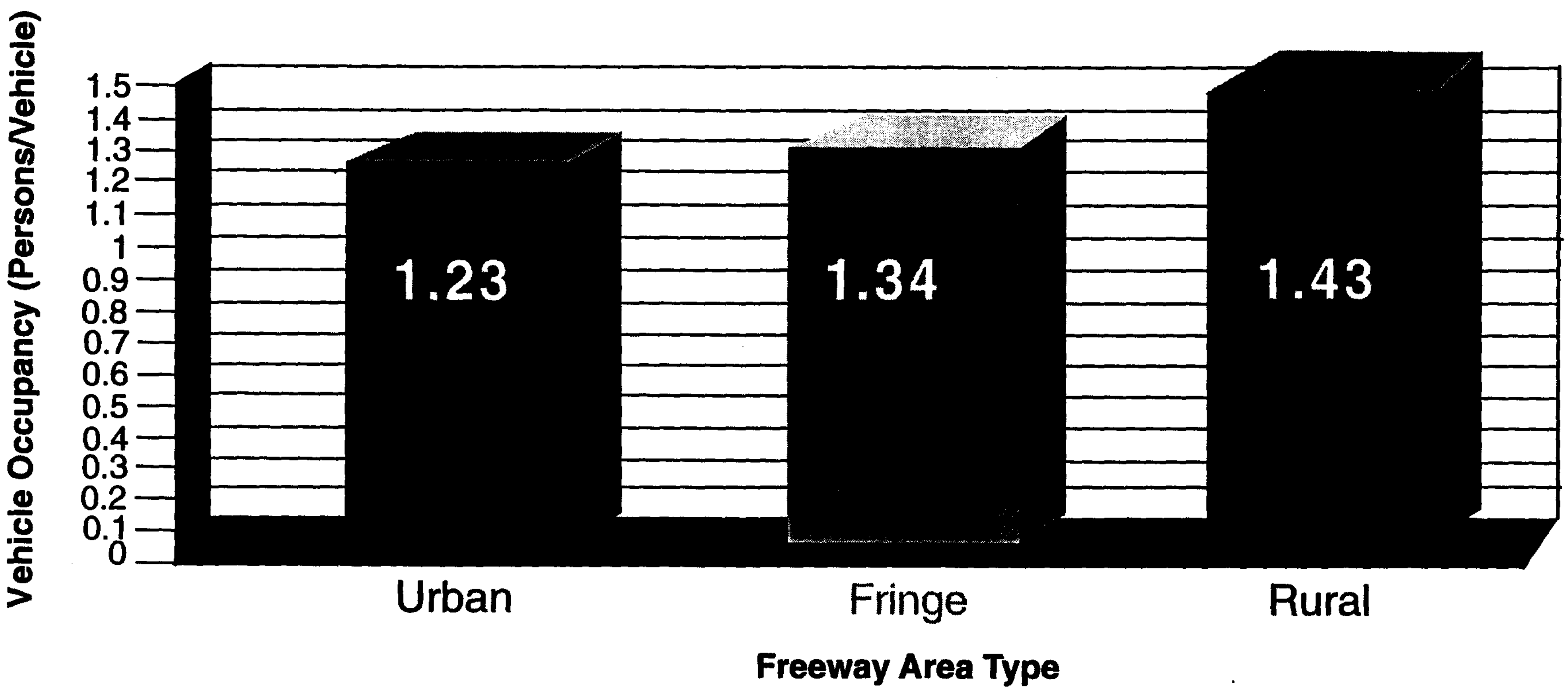


Figure 27. Average freeway peak hour travel speeds by area type.



Source: Minneapolis/St. Paul Metropolitan Council - 1991 Travel Behavior Inventory

Figure 28. Average freeway vehicle occupants by area type.

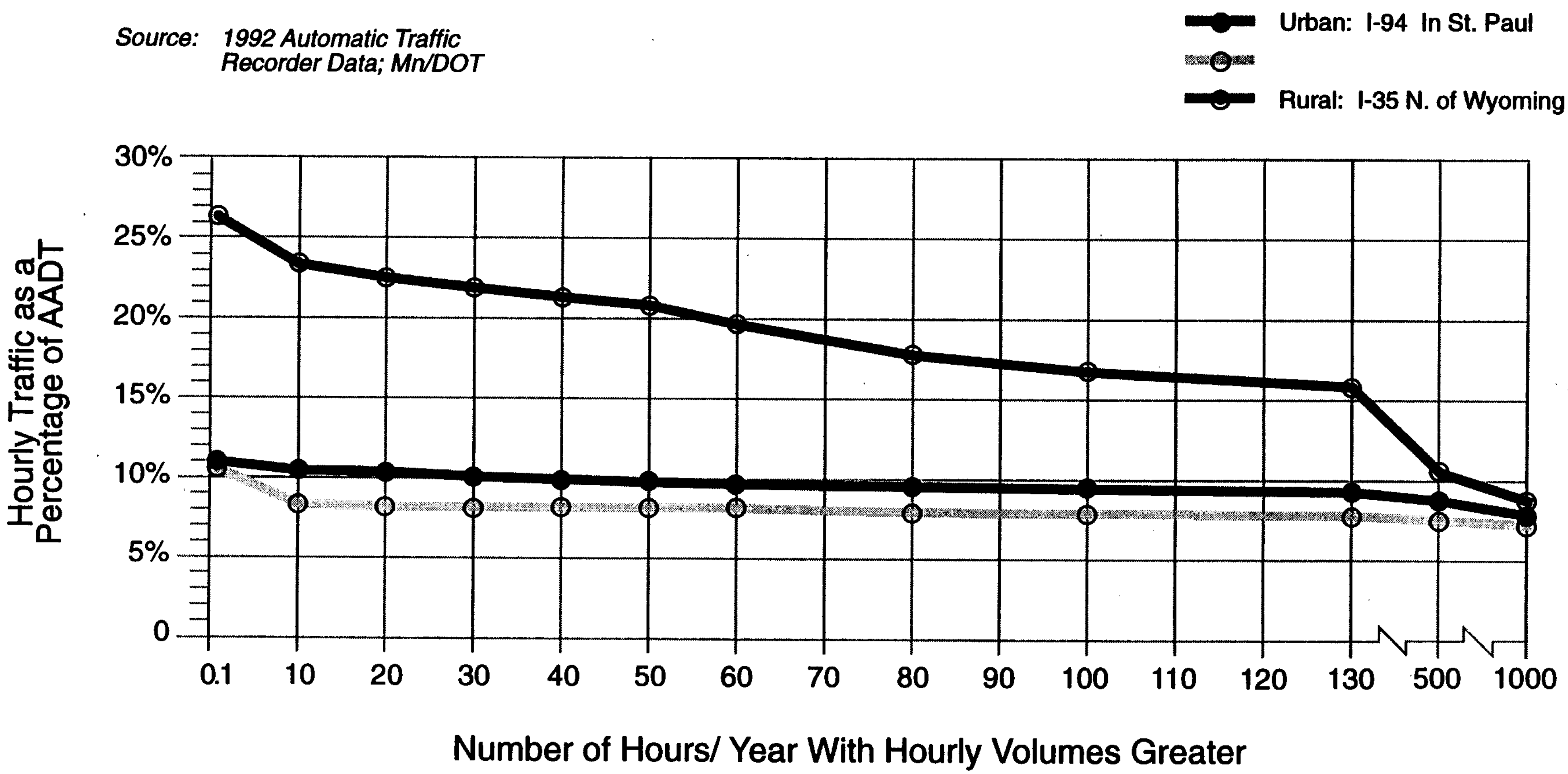


Figure 29. Relationship between peak hour and AADT by area type.

Traffic Variations

The daily and monthly traffic variations along three typical urban, fringe, and rural freeways within the State of Minnesota are shown in figure 30. The data indicate that the traffic demand on rural freeways is typically below average Sunday through Thursday and above average on Friday and Saturday, with Friday traffic significantly above average. The data also indicates that the traffic demand on urban and fringe freeways is typically above average on weekdays and below average on weekends.

The monthly traffic variations shown in figure 30 indicate that rural freeway segments typically have lower traffic demands from November to April and above average demands from May through October. The urban and fringe freeways typically exhibit fairly constant monthly traffic demands throughout the year.

The hourly traffic variations on an average weekday along three typical urban, fringe and rural freeways within the State of Minnesota are shown in figure 31. The data indicate that the hourly traffic demands on rural freeways are fairly constant with only minor peaking while the urban and fringe freeways typically experience two noticeable traffic peaks (AM and PM) and much higher traffic demands during the working hours. The AM and PM peak hours of weekday traffic demand are from approximately 7:00 to 8:00 a.m. and 4:00 to 5:00 p.m. for each freeway area type.

The hourly traffic variations on an average Saturday along three typical urban, fringe and rural freeways within the State of Minnesota are shown in figure 32. The data indicate that the hourly traffic demand on rural freeways is fairly constant with only marginal peaking while the urban and fringe freeways typically experience a gradual traffic growth to roughly 11:00 a.m. and relatively constant traffic demand during the afternoon hours before declining in the evening hours. The peak traffic demand hour on a typical Saturday is from noon to 1:00 p.m.

Ramp Capacity

The approximate service flow rates for single lane ramps are shown in table 9. The data indicate that the capacity of a single lane ramp is dependent upon the design speed of the ramp, with the capacity of a loop approximating 1,300 passenger cars per hour (pcph) and the capacity of a straight ramp near 1,700 pcph. Adjustment factors are also provided for estimating the capacities of two lane ramps.

The ramp capacities noted above assume that there are no ramp meters. If ramp meters are present, the ramp capacities are directly related to the cycle length of the meter, the number of lanes and the meter rules. The cycle lengths for one lane metered ramps in the Minneapolis/St. Paul area range from 4.5 to 18 seconds. This equates to service flow rates from 200 vehicles per hour (vph) to 800 vph. Two lane metered ramps in the Minneapolis/St. Paul area typically accommodate from 1,600 vph (alternating signals—4.5 second cycle) to 2,200 vph (two cars per green).

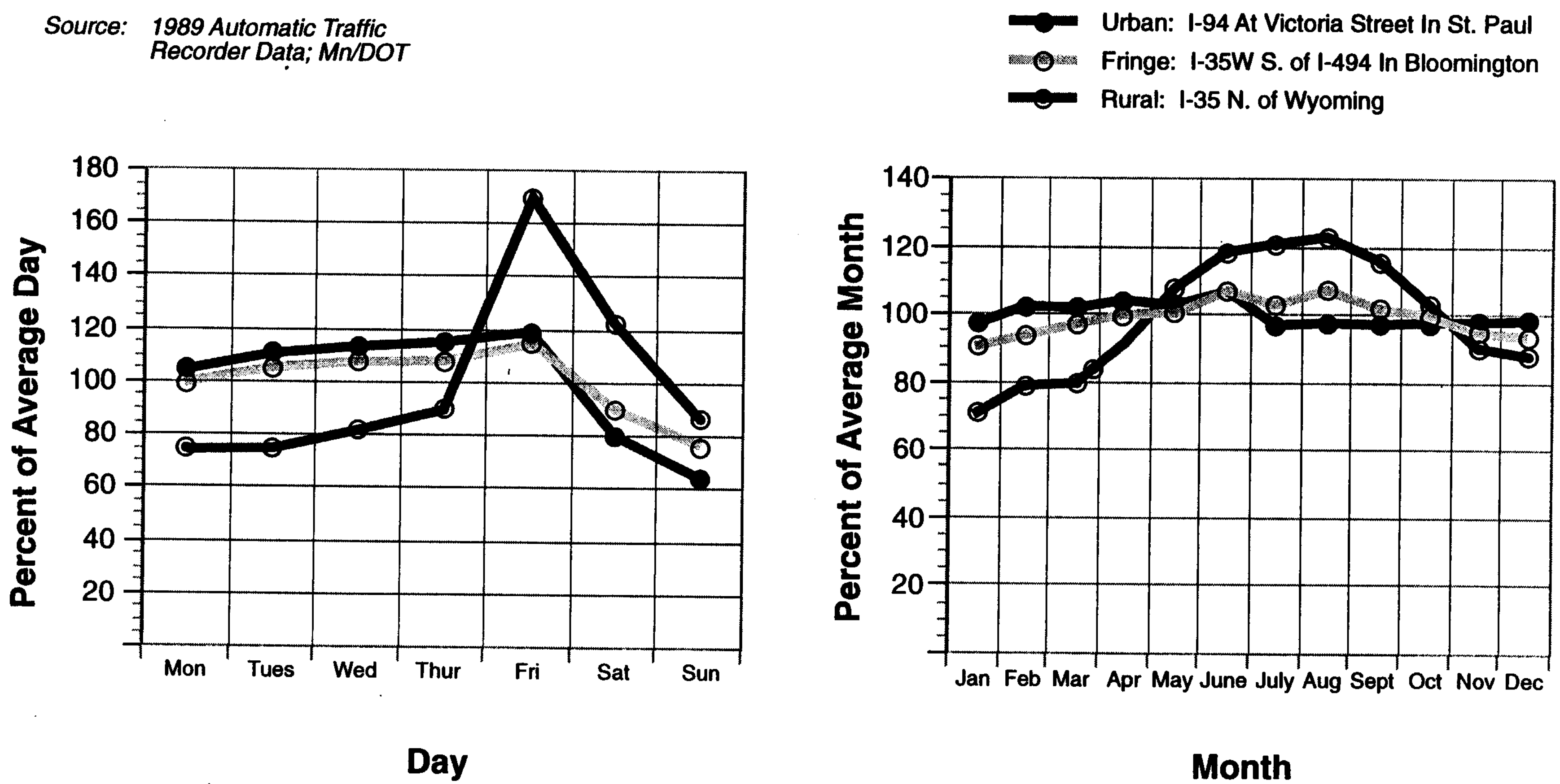


Figure 30. Monthly and daily traffic variations by freeway area type.

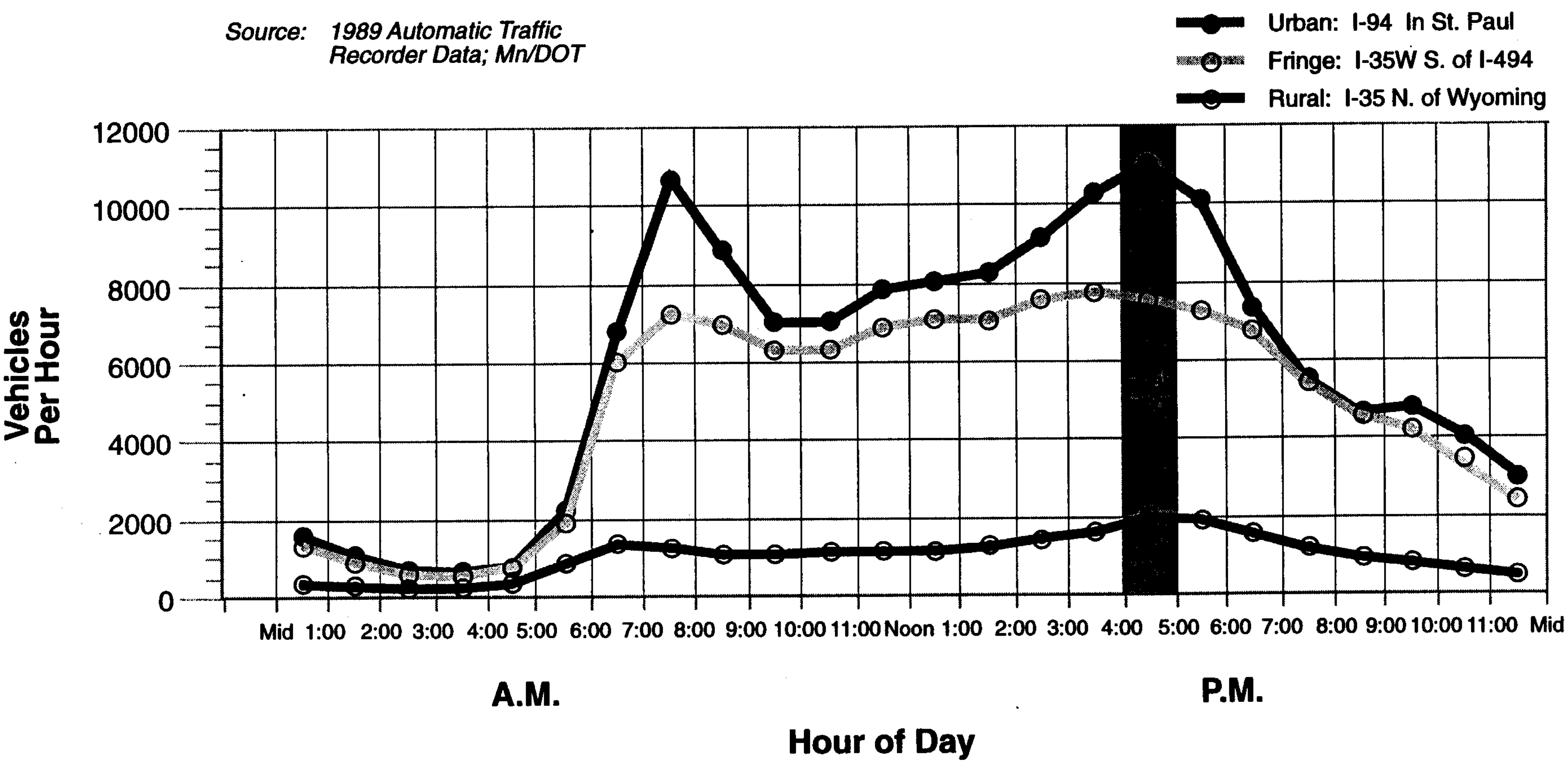


Figure 31. Hourly traffic variations on an average weekday.

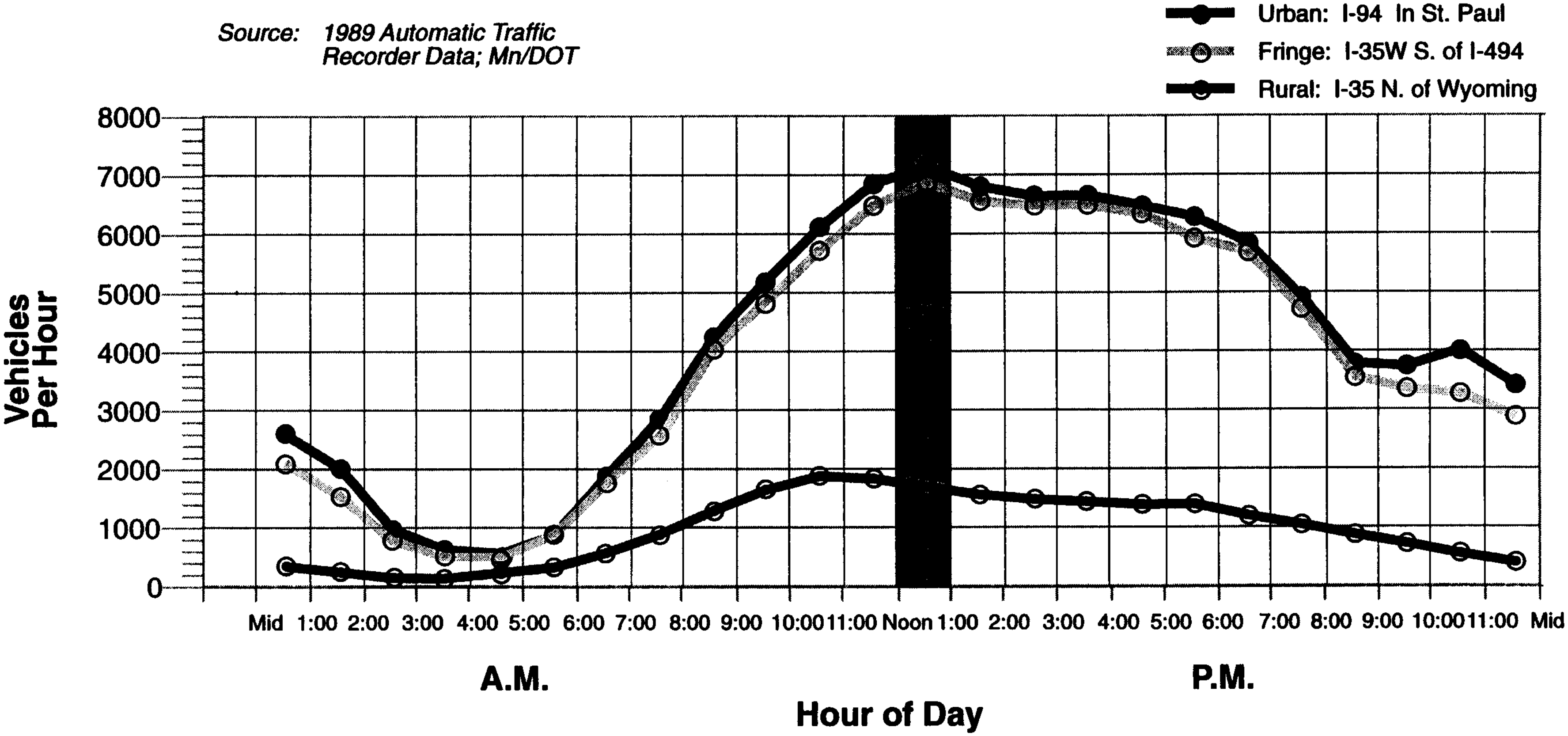


Figure 32. Hourly traffic variations on an average Saturday.

Table 9. Approximate service flow rates for single-lane ramps.

LOS	Ramp Design Speed (MPH)				
	≤ 20	21-30	31-40	41-50	≥ 51
A	b	b	b	b	600
B	b	b	b	900	900
C	b	b	1,100	1,250	1,300
D	b	1,200	1,350	1,550	1,600
E	1,250	1,450	1,600	1,650	1,700
F	Widely Variable				

[a]For two-lane ramps, multiply the values in the table by: 1.7 for ≤ 20 mph
1.8 for 21-30 mph
1.9 for 31-40 mph
2.0 for ≥ 41 mph

[b]Level of service not attainable due to restricted design speed.

Source: 1985 Highway Capacity Manual.

Observed Ramp Volume Ranges within Twin Cities Area*

- One Lane Metered: 200 (18 second cycle) - 800 vph (4.5 second cycle)
- One Lane Not Metered: Up to 1,700 vph
- Two Lane Metered: Up to 1,600 vph (Alternating signals - 4.5 second cycle)
- Two Lane Metered: Up to 2,200 vph (Two cars per green)

*Based on single-lane merge condition onto freeway.

Source: Mn/DOT Traffic Management Center

Effects of Freeway Traffic Management

The Minnesota Department of Transportation has implemented several freeway traffic management systems along the interstate segments within and surrounding the Minneapolis/St. Paul Metropolitan Area. The first four (I-35E, I-35W, I-694 and I-494) systems were analyzed using before and after studies to determine the system benefits. The limits and components of these four systems are shown in figure 33 and table 10, respectively. Table 10 indicates that all of the systems were equipped with detectors and ramp meters and that some systems also include video cameras, highway advisory radio, changeable message signs, express bus service and HOV bypass lanes. The traffic flow benefits of implementing these four traffic management systems are discussed in the following paragraphs. These Before/After Study benefits are based on data provided by the Mn/DOT Traffic Management Center.

Delay: The peak period vehicle delay before and after the implementation of the four traffic management systems is shown in table 11. The data indicate that the delay decreased significantly along each freeway segment. The actual delay decreases ranged from 20 percent along I-35W to 77.1 percent along I-35E and the average decrease in delay across the entire system was approximately 25 percent.

Speed: The peak period travel speeds before and after the implementation of the four traffic management systems is shown in figure 34. The data indicate that the speed increased noticeably on three of the four freeway segments and that the slight after condition speed reduction on I-694 was the result of the limited capacity of a major river crossing. The speed increases ranged from 3.0 mph along I-494 to 7.9 mph along I-35W.

Volumes: The average peak period traffic demand volumes before and after the implementation of traffic management systems on the four freeway segments is shown in figure 35. The data indicate that the delay, speed and accident benefits were all achieved even though there was a significant increase in traffic demand.

Accident Characteristics

The accident data used to determine accident frequencies, rates, types and severities was obtained from the Mn/DOT Office of Traffic Engineering. This data reflects the 1990 through 1992 interstate freeway accident experience within the State of Minnesota.

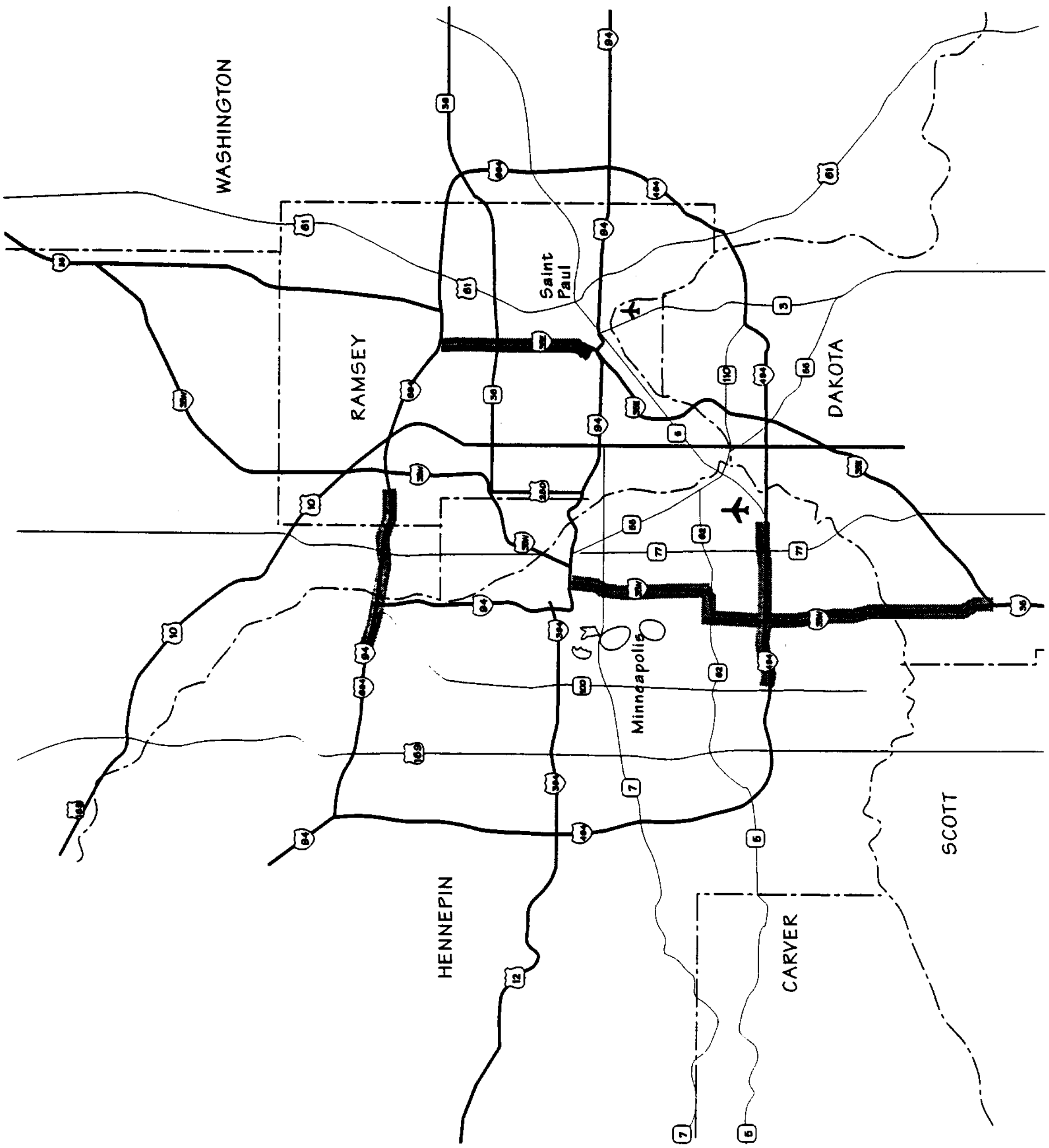


Figure 33. Location of traffic management systems within metro area (1990).

Table 10. Summary of traffic management system components.

Route	Vehicle Detectors	Surveillance	Highway Advisory Radio	Metered Ramps	Changeable Message Signs	Express Bus	Bypass Lanes
	System Components*						
I-35E (1974)**	●			●			
I-35W (1978)**	●	●	●	●	●	●	●
I-694 (1983)**	●			●	●		
I-494 (1990)**	●			●	●		●

* At time of Analysis
** Year Implementation Completed

Table 11. Delay before and after implementation of traffic management system.

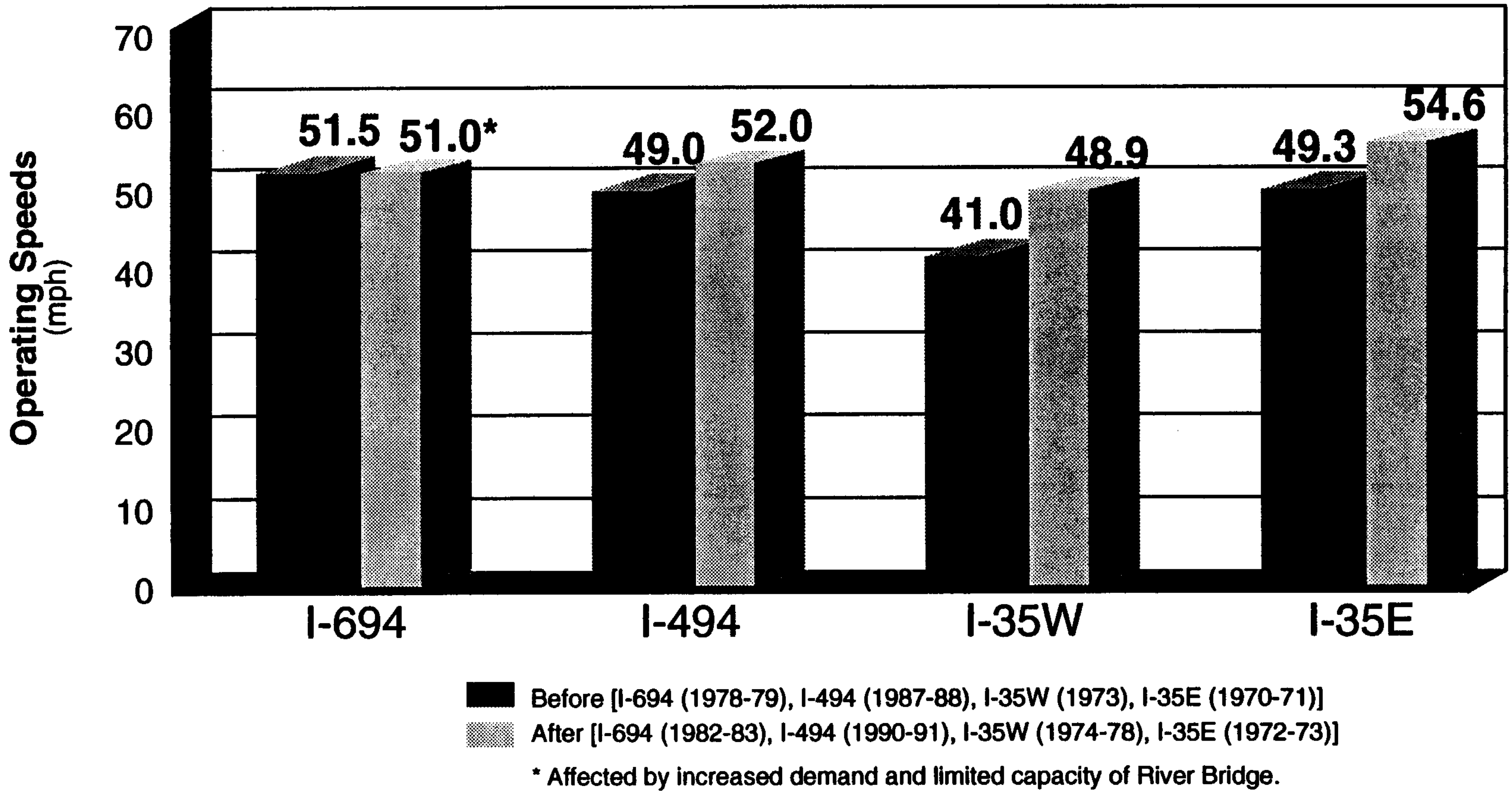
Route	Mainline Delay (Vehicle - Hrs.) Before	After
I-694 (1)	222.77	134.16 (-39.8%)
I-494	N.A.	N.A.
I-35W (2)	2,000	1,600 (-20.0%)
I-35E (3)	89.9	20.6 (-77.1%)

1) Both Directions - Both Peak Periods.

2) One Direction - Both Peak Periods.
Estimated based on travel time and volume data documented in the "Summary of Operation Experience 1974 - 1978".

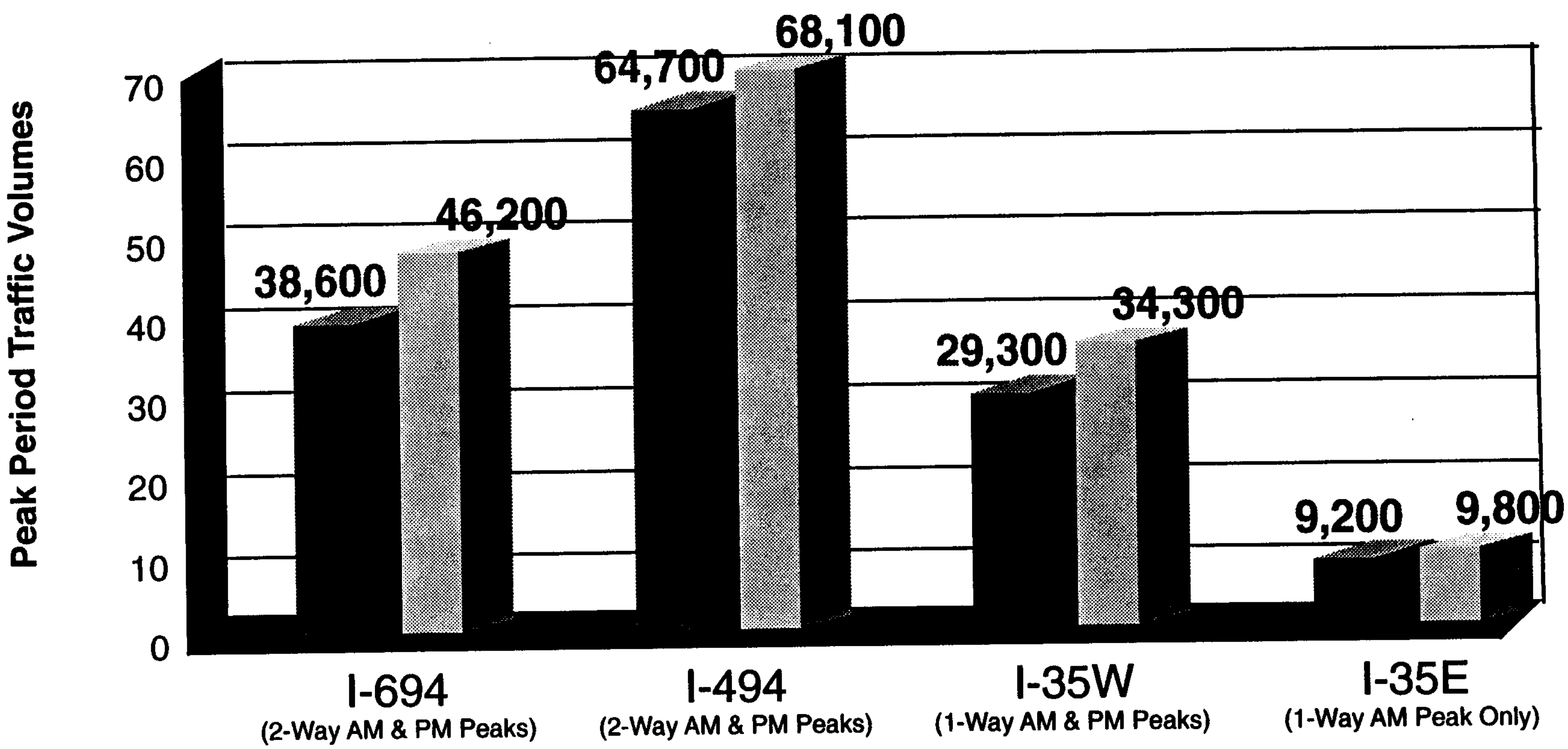
3) Southbound AM Peak Only.

Source: Mn/DOT Traffic Management Center



Source: Mn/DOT Traffic Management Center

Figure 34. Travel speeds before and after implementation of traffic management systems.



Source: Mn/DOT Traffic Management Center

Figure 35. Traffic volumes before and after implementation of traffic management systems.

Accident Rates

The average annual freeway accident rates and frequencies by area type are shown in figure 36. The data indicate that the accident rates range from 0.7 accidents per million vehicle miles (acc/MVM) travelled on rural freeway segments to 1.7 acc/MVM on urban segments and that the annual number of accidents ranged from 1,988 on rural freeways to 3,210 on urban freeways.

In order to determine whether Minnesota's freeway accident characteristics are similar to other states accident experience, additional accident rate data was also obtained from the Arizona Department of Transportation (ADOT) and the Colorado Department of Highways (CDOH). This data indicates that the ADOT rates of 0.6 acc/MVM on rural freeways and 1.2 acc/MVM on urban freeways and the CDOH rates of 0.8 acc/MVM on rural freeways and 1.7 acc/MVM on urban freeways are similar to the Mn/DOT rates.

Accident Types

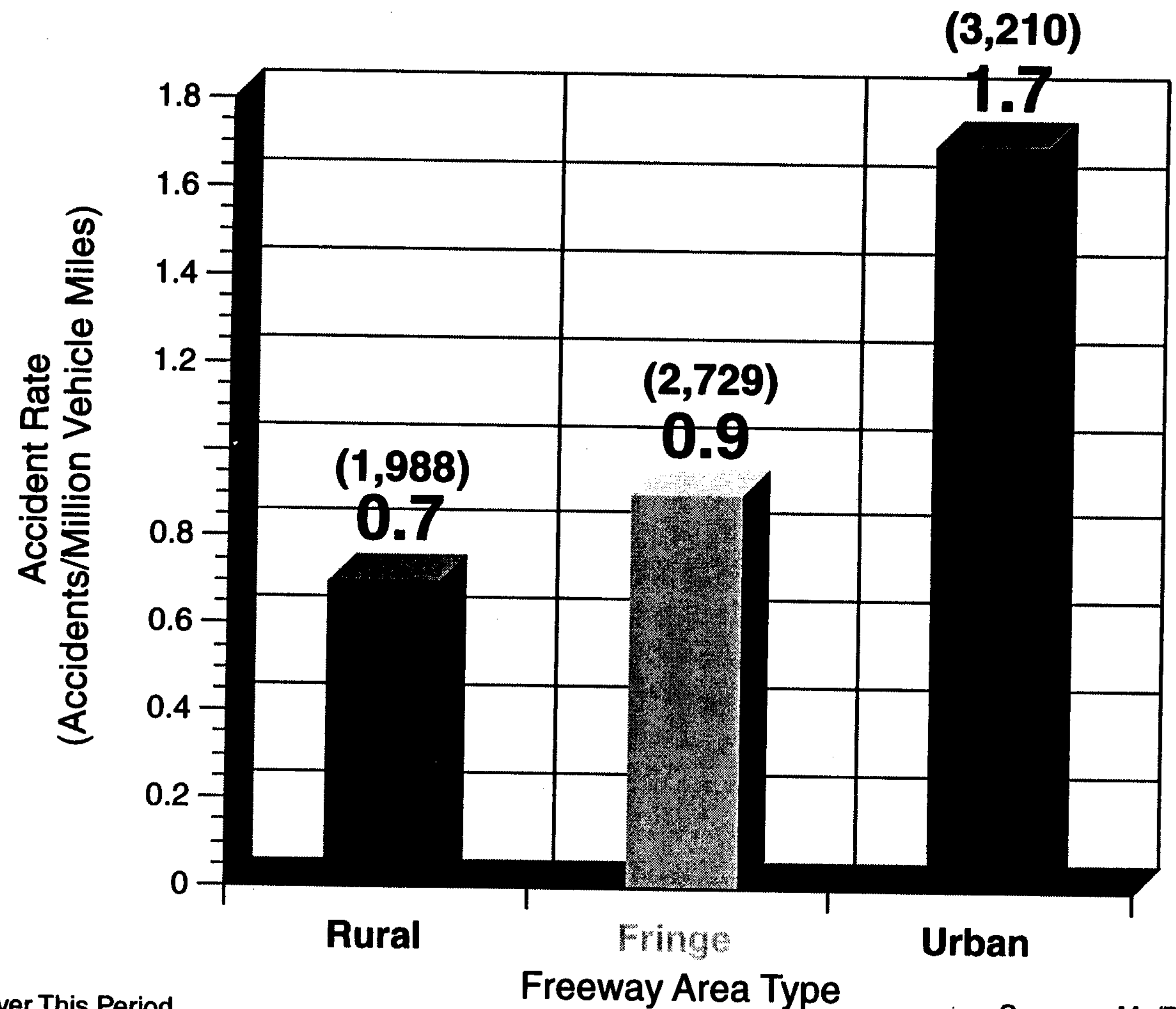
The types of accidents that have occurred on the urban, fringe and rural interstate freeways within the State of Minnesota are shown in figures 37, 38, and 39, respectively. This data represents the annual average number of accidents of each type over the 1990 to 1992 time period.

Figure 37 indicates that “rear-end” accidents were the predominant accident type on urban freeways, accounting for over half of the accidents. Sideswipe accidents were the second most common accident type along urban freeways, followed by single vehicle run off the road accidents.

Figure 38 indicates that “rear-end” accidents were also the predominant accident type along fringe freeway segments, accounting for over 40 percent of the total accidents. The “other/unknown” accidents comprise the second most common accident types along fringe freeway segments, with over 32 percent of these “Other/Unknown” accidents involving “deer/other animal” hits. Side swipe accidents and single vehicle run off the road accidents were the next most common types.

Figure 39 indicates that the “other/unknown” accidents represented the most predominant accident type on rural freeways and that approximately 70 percent of these accidents, or 25 percent of the total rural freeway accidents, were “deer/other animal” accidents. The second most common accident type along rural freeways were “ran-off-road” accidents, which accounted for roughly 34 percent of the total rural freeway accidents.

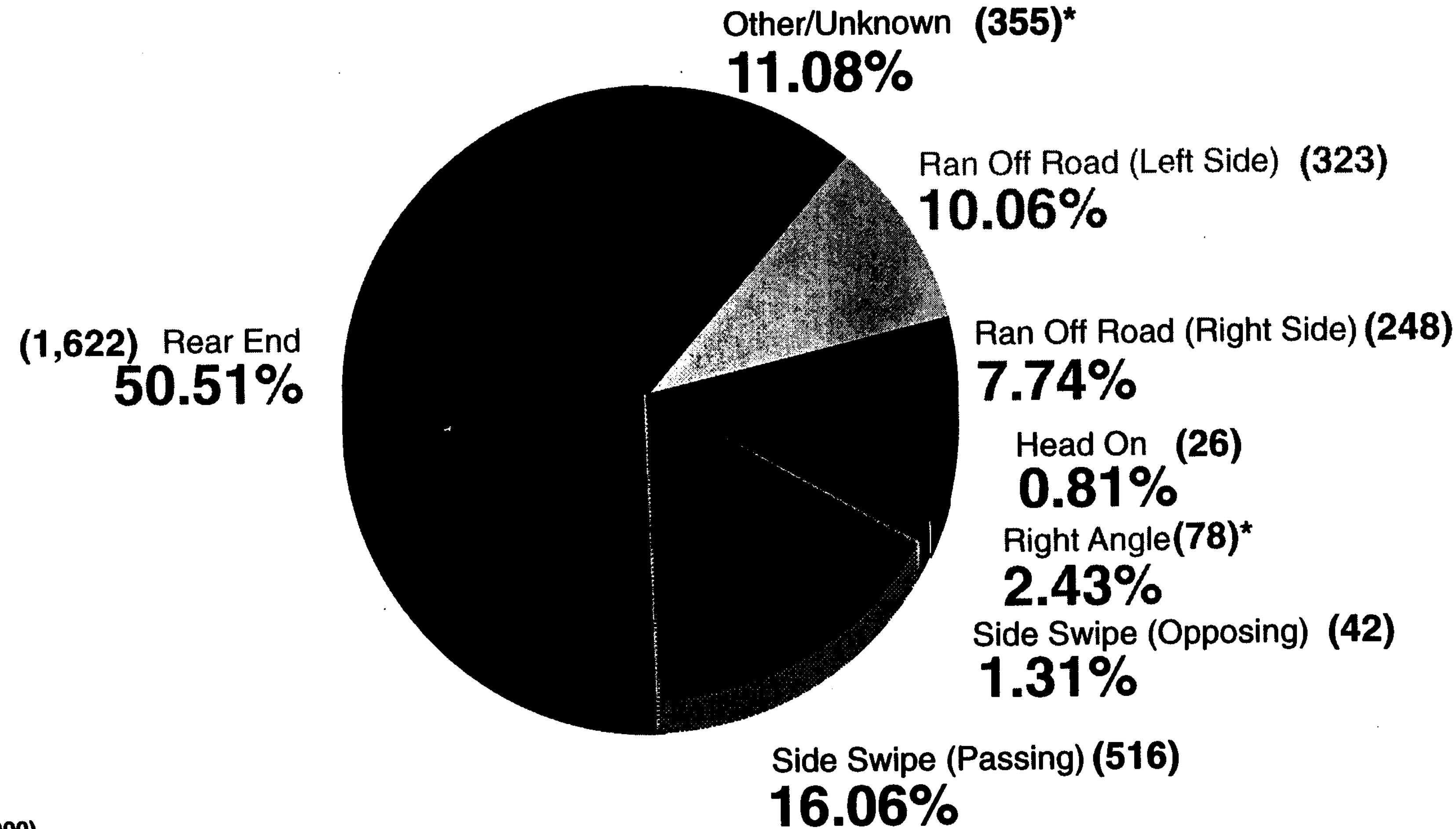
A comparative summary of the accident type percentages on the urban, fringe and rural interstate freeway segments is shown in figure 40.



(000) Accidents Over This Period
Annual Average Number of Reported

Source: Mn/DOT Metro Division Office of Traffic Engineering.

Figure 36. Freeway accident rates (Minnesota 1990-1992).

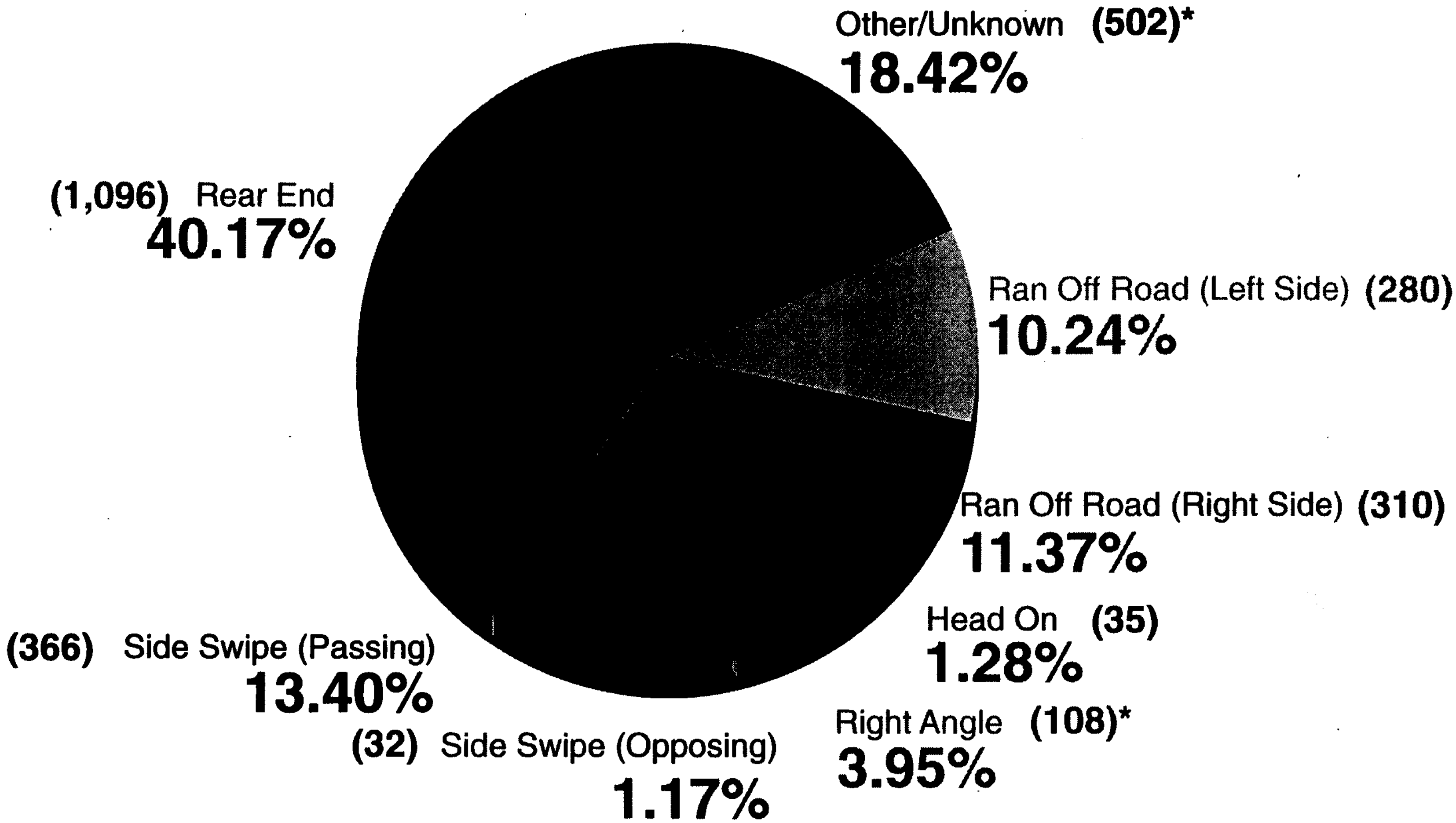


(000)
By Type Over This Period
Annual Average Number of Accidents

* Includes Deer/Other Animal Accidents
Annual Average of 13 Animal Accidents Over this Period.

Source: Mn/DOT Metro Division Office of Traffic Engineering.

Figure 37. Freeway accident types (Minnesota 1990-1992)—urban areas.

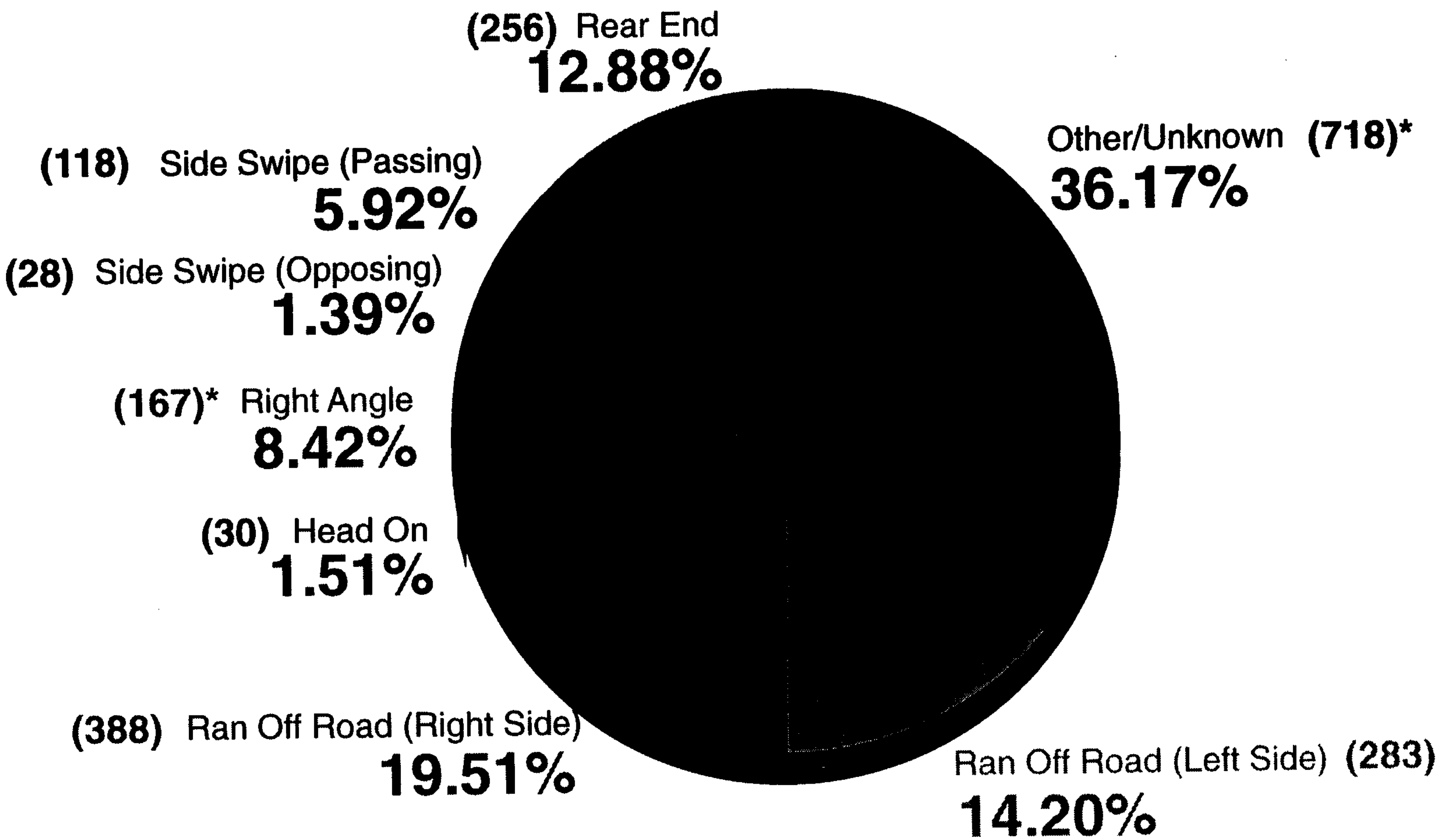


(000) Annual Average Number of Accidents By Type Over This Period

* Includes Deer/Other Animal Accidents Annual Average of 162 Animal Accidents Over this Period.

Source: Mn/DOT Metro Division Office of Traffic Engineering.

Figure 38. Freeway accident types (Minnesota 1990-1992)—fringe area.



(000) Annual Average Number of Accidents By Type Over This Period

* Includes Deer/Other Animal Accidents
Annual Average of 499 Animal Accidents Over this Period.

Source: Mn/DOT Metro Division Office of Traffic Engineering.

Figure 39. Freeway accident types (Minnesota 1990-1992)—rural areas.

Source: State of Minnesota (1990 - 1992) Mn/DOT Metro
Division Office of Traffic Engineering

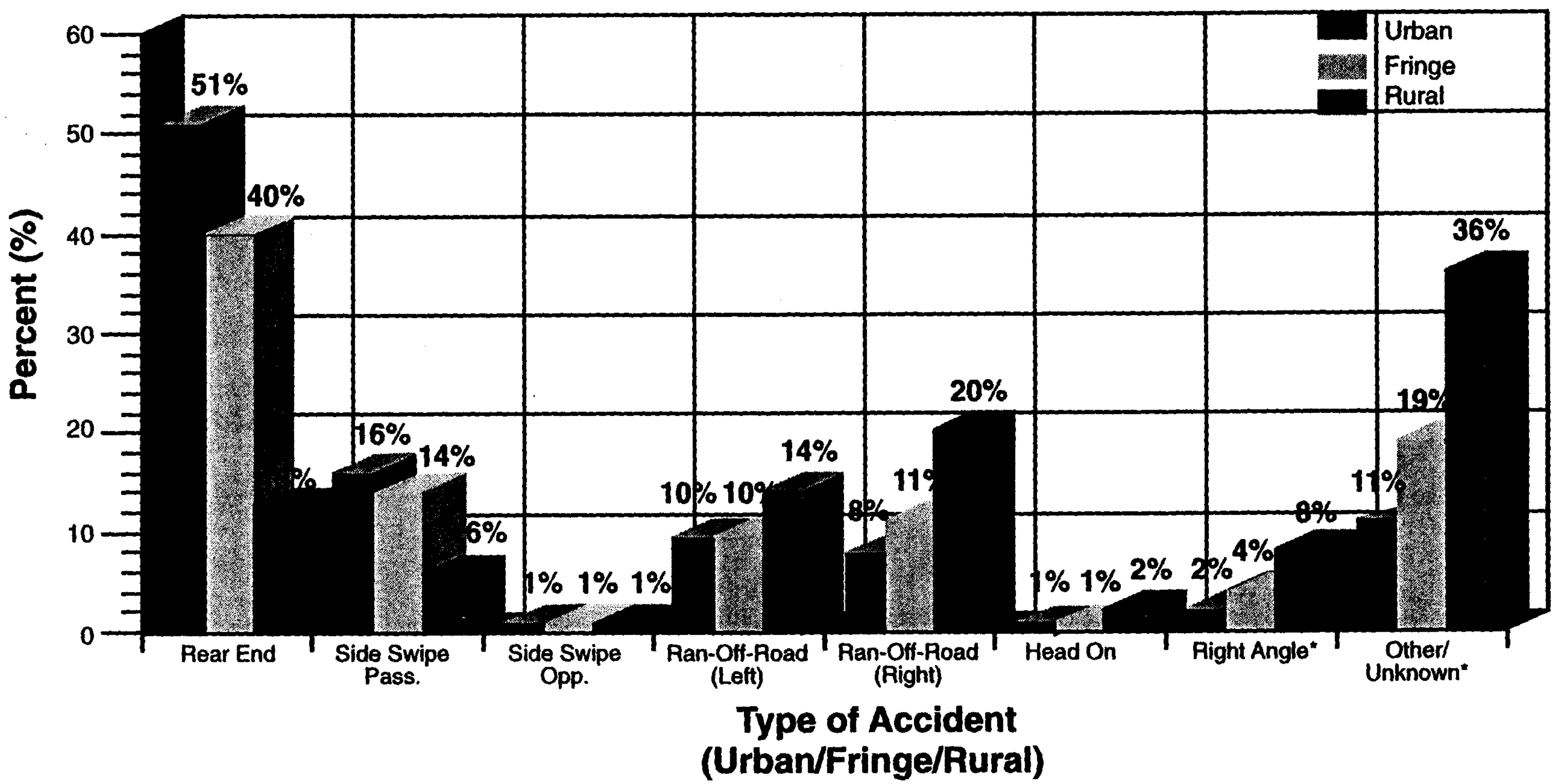


Figure 40. Types of freeway accidents.

Accident Severity

The severity of accidents on Minnesota urban, fringe and rural interstate freeways is shown in figure 41. This data reflects the annual average number and percentage of fatal, injury and property damage only (PDO) accidents by freeway area type.

The data indicate that the rural freeway segments had the highest percentage of fatal accidents (0.87 percent) and that the fringe freeway segments had the highest percentage of fatal plus injury accidents (24.91 percent). PDO accidents accounted for roughly 75 percent of the total accidents on each freeway area type.

Ramp Accidents

The accident rates of freeway ramps by ramp type are shown in figure 42. This data was obtained from Federal Highway Administration publication FHWA-RD-91-047.

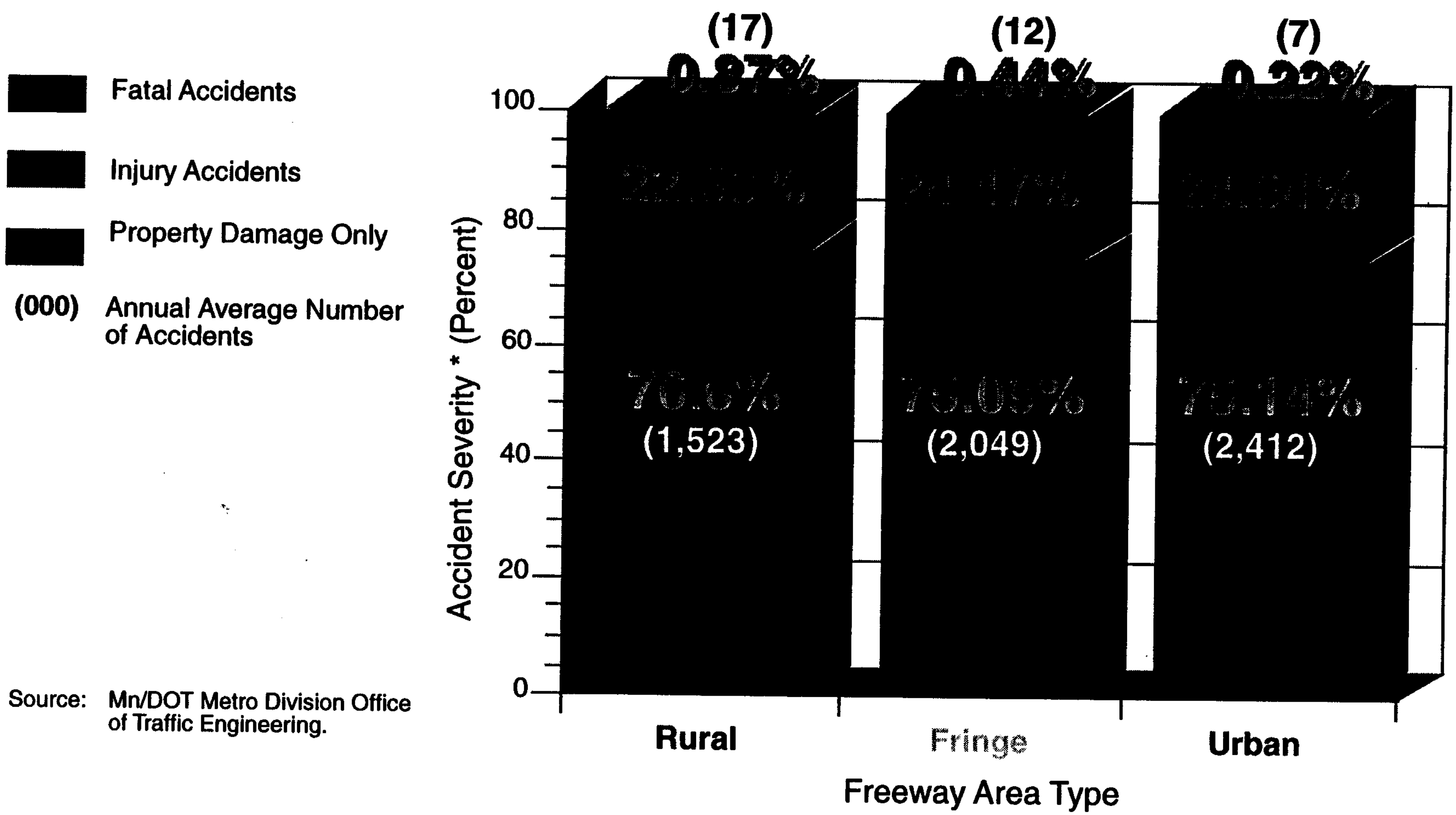
The data indicate that the rates of left side ramps and scissors ramps have the highest accident rates and that cloverleaf loops and ramps with collector/distributor roads and diamond ramps have the lowest accident rates. The data also indicate that the average accident rates for on-ramps is 0.59 accidents per million vehicles (acc/MV) and that the average rate for off-ramps is 0.95 acc/MV.

Effects of Freeway Traffic Management

The accident benefits associated with implementation of a freeway traffic management system along I-35E, I-35W, I-694 and I-494 are discussed in the following paragraphs. This information is based on data provided by the Mn/DOT Traffic Management Center.

Number of Accidents: The annual average number of peak period accidents before and after the implementation of the traffic management systems (TMS) is shown in figure 43. The data indicate that the number of traffic accidents decreased along all freeway segments following the implementation of the TMS's by between 15 and 36 percent, with an overall system wide average of 22 percent.

Accident Rates: The average peak period accident rates before and after the implementation of the TMS is shown in figure 44. The data indicate that the accident rates decreased along all four freeways following the implementation of the TMS's. The data also indicate that the accident rates reduction percentages were approximately 27 percent for the fringe freeway segments (I-494 and I-694) and 31 percent for the urban freeway segments (I-35E and I-35W).



Source: Mn/DOT Metro Division Office of Traffic Engineering.

Figure 41. Freeway accident severity (Minnesota 1990-1992).

Source: Federal Highway Administration, publication FHWA-RD-91-047

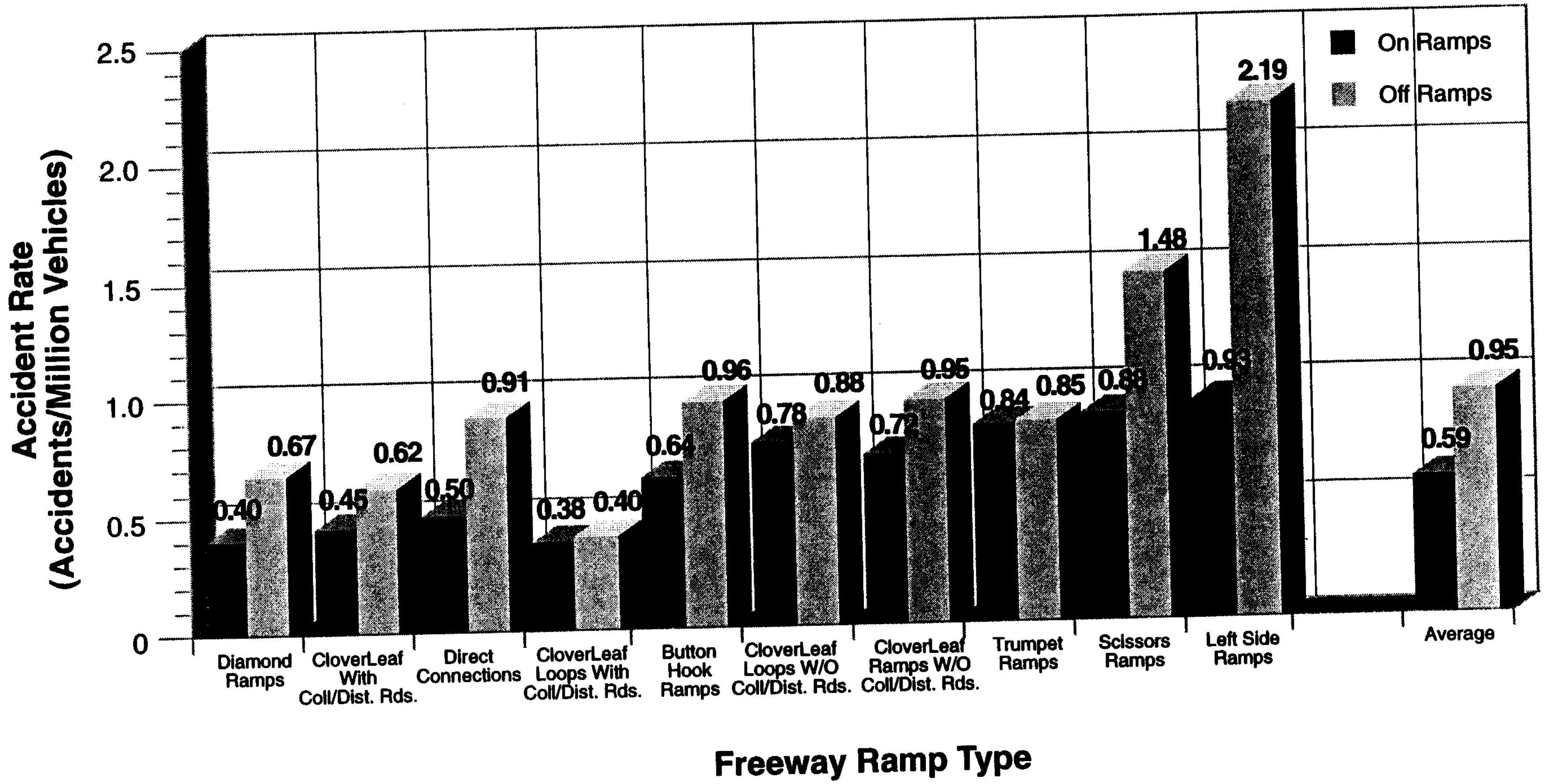
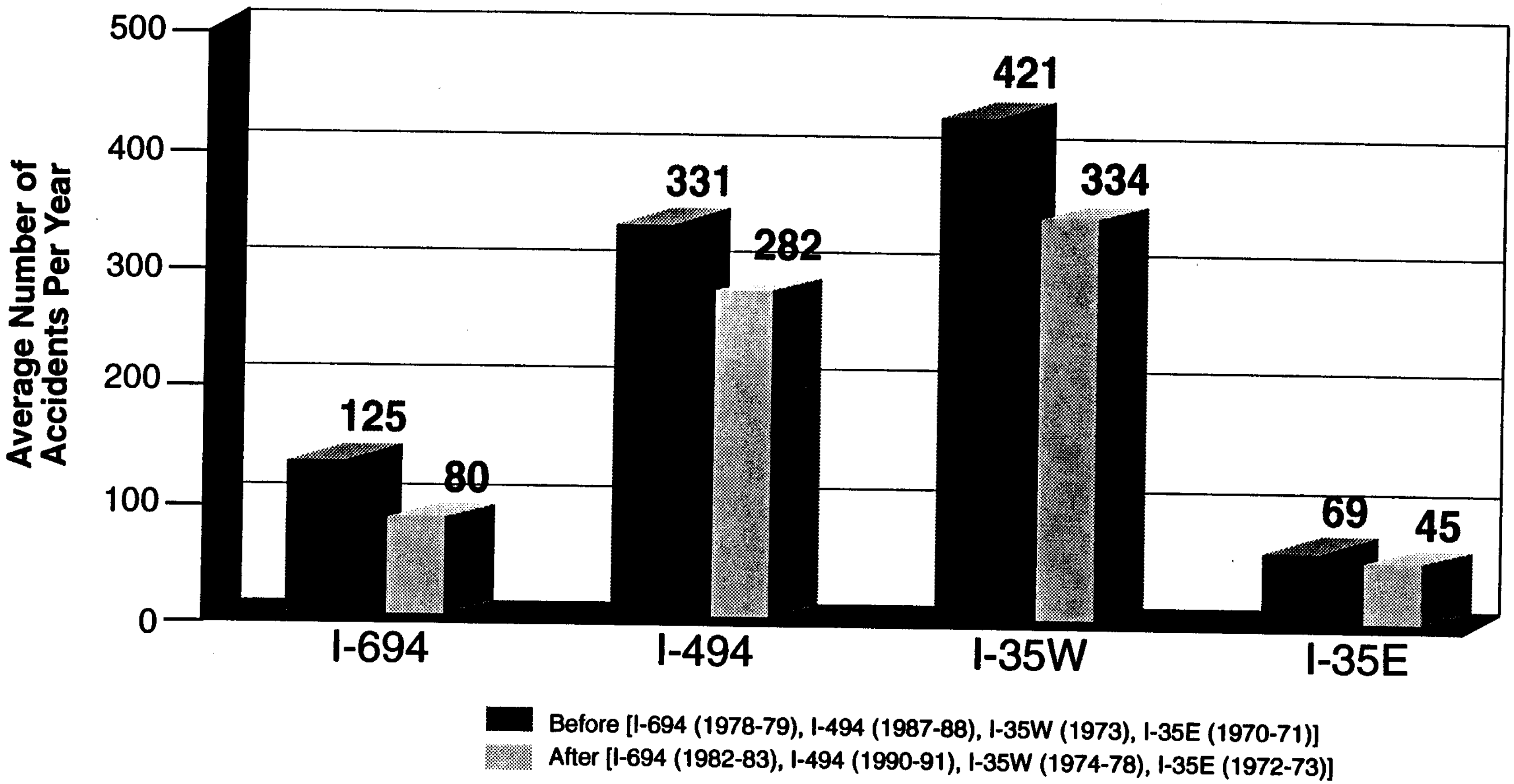
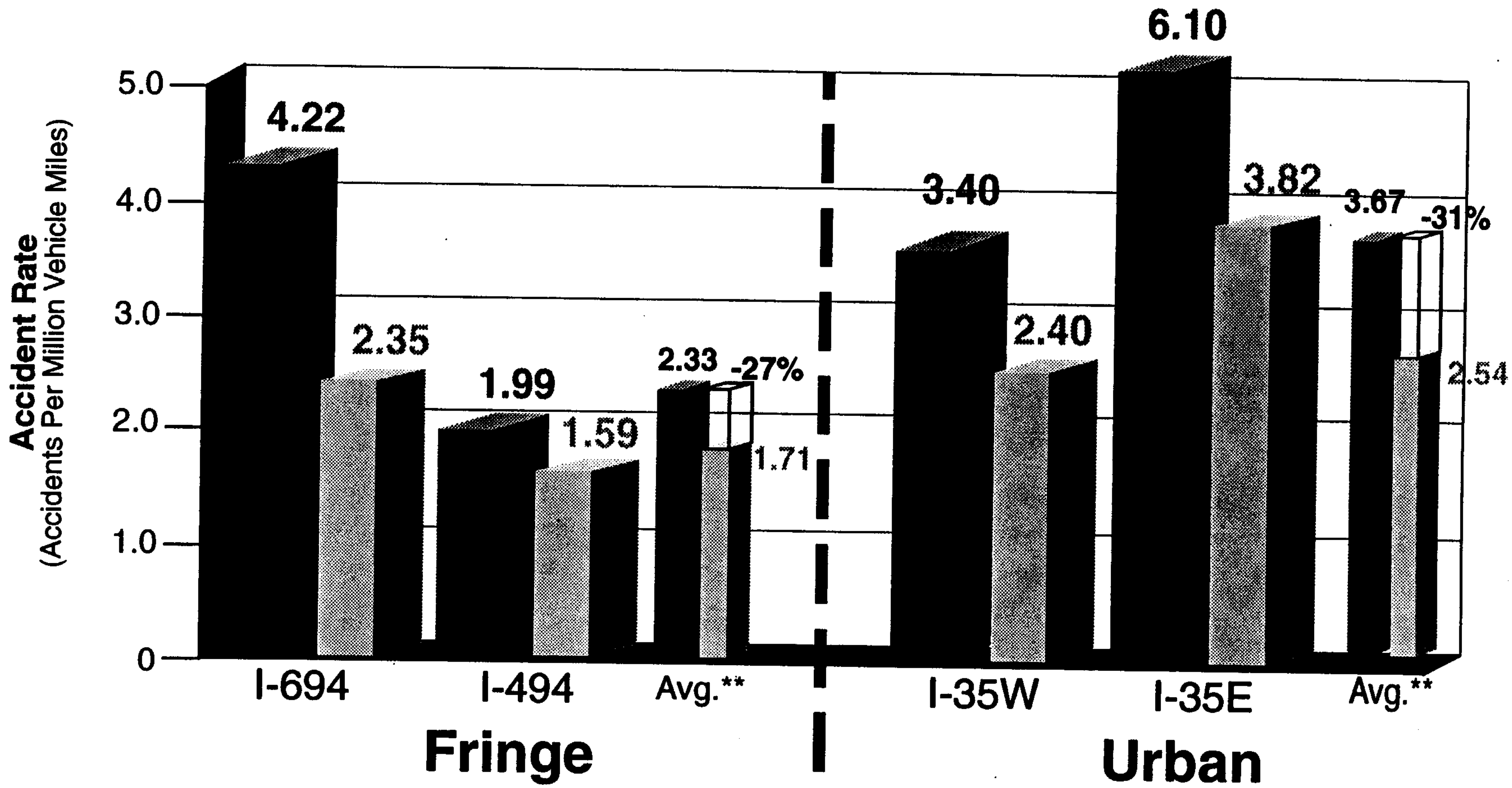


Figure 42. Accident rates by type of freeway ramps.



Source: Mn/DOT Traffic Management Center

Figure 43. Annual average number of accidents before and after implementation of traffic management systems.



Source: Mn/DOT Traffic Management Center

Before [I-694 (1978-79), I-494 (1987-88), I-35W (1973), I-35E (1970-71)]
After [I-694 (1982-83), I-494 (1990-91), I-35W (1974-78), I-35E (1972-73)]

* No Data Available for Rural Systems
** Weighted by Expousure

Figure 44. Annual average peak period accident rates before and after implementation of traffic management systems by freeway area types.

Accident Types: The annual average peak period accident type percentages before and after the implementation of the TMS is shown in figure 45. This data was not surveyed or documented in the I-494 study. The data indicates that there was a slight reduction in rear end accidents but there was no a significant change in the overall distribution of accident types.

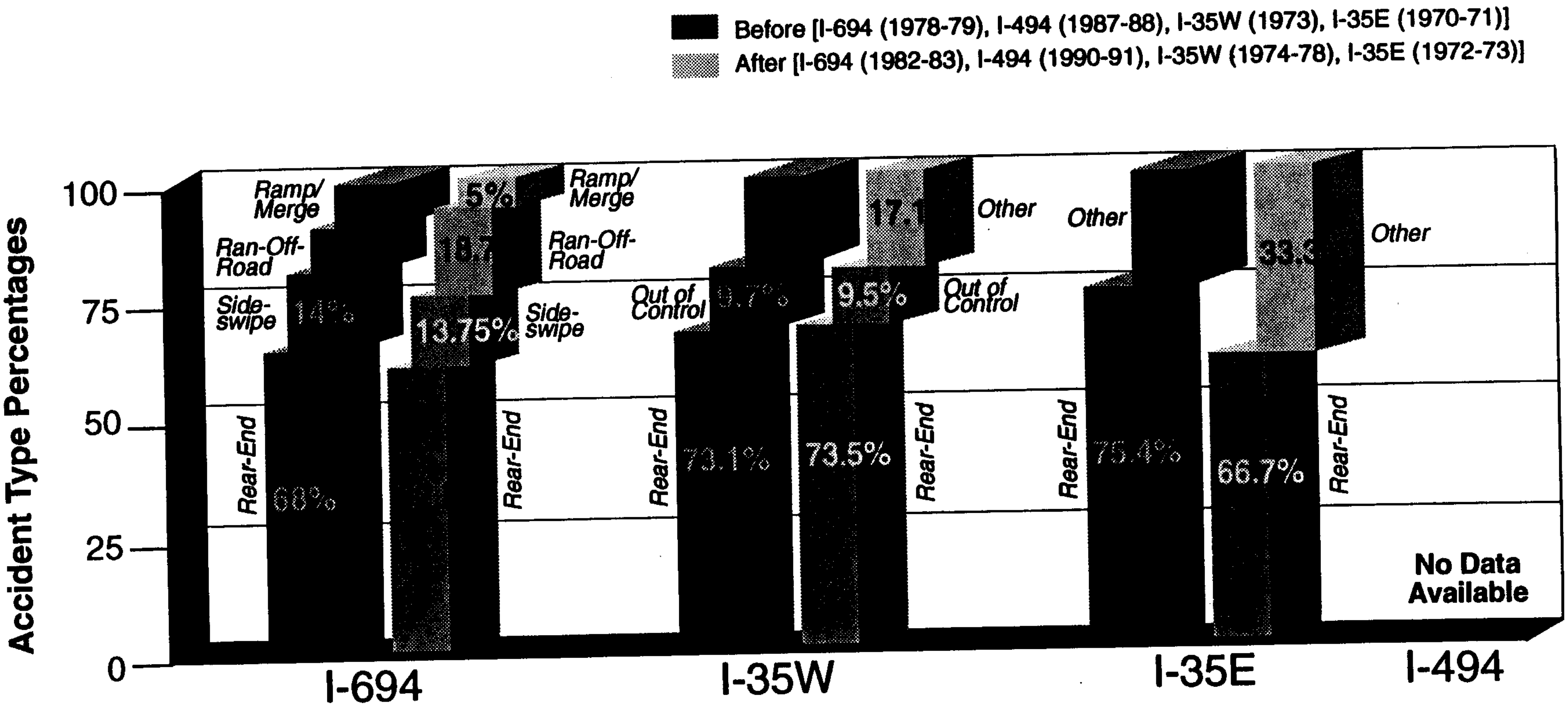
Accident Severity: The average distribution of peak period accident severity before an after the implementation of TMS on I-35E and I-35W are shown in figure 46. This data was not surveyed or documented in the I-694 and I-494 studies. The data indicate that there was a significant decrease in both property claimage (17 percent) and injury accidents (40 percent) since the TMS's were implemented.

Long-Term Accident Benefits: The long-term accident trends associated with implementing a traffic management system were analyzed to determine if the previously documented accident reductions decrease or are eliminated over time. The I-35W system was analyzed for this purpose because it is the longest established and most extensive TMS in the Minneapolis/St. Paul area and because long term accident data was available.

The peak period accident rates along I-35W before and after the implementation of the I-35W TMS are shown in figure 47. The data indicate that, the accident rates have continued to decrease over the 20 years since implementation. The average accident rate for the first five years after implementation (2.4 accident/MVM) is 30 percent less than the before average and the rate from the most recent five year period (1.7 accident/MVM) is 50 percent less than the before average.

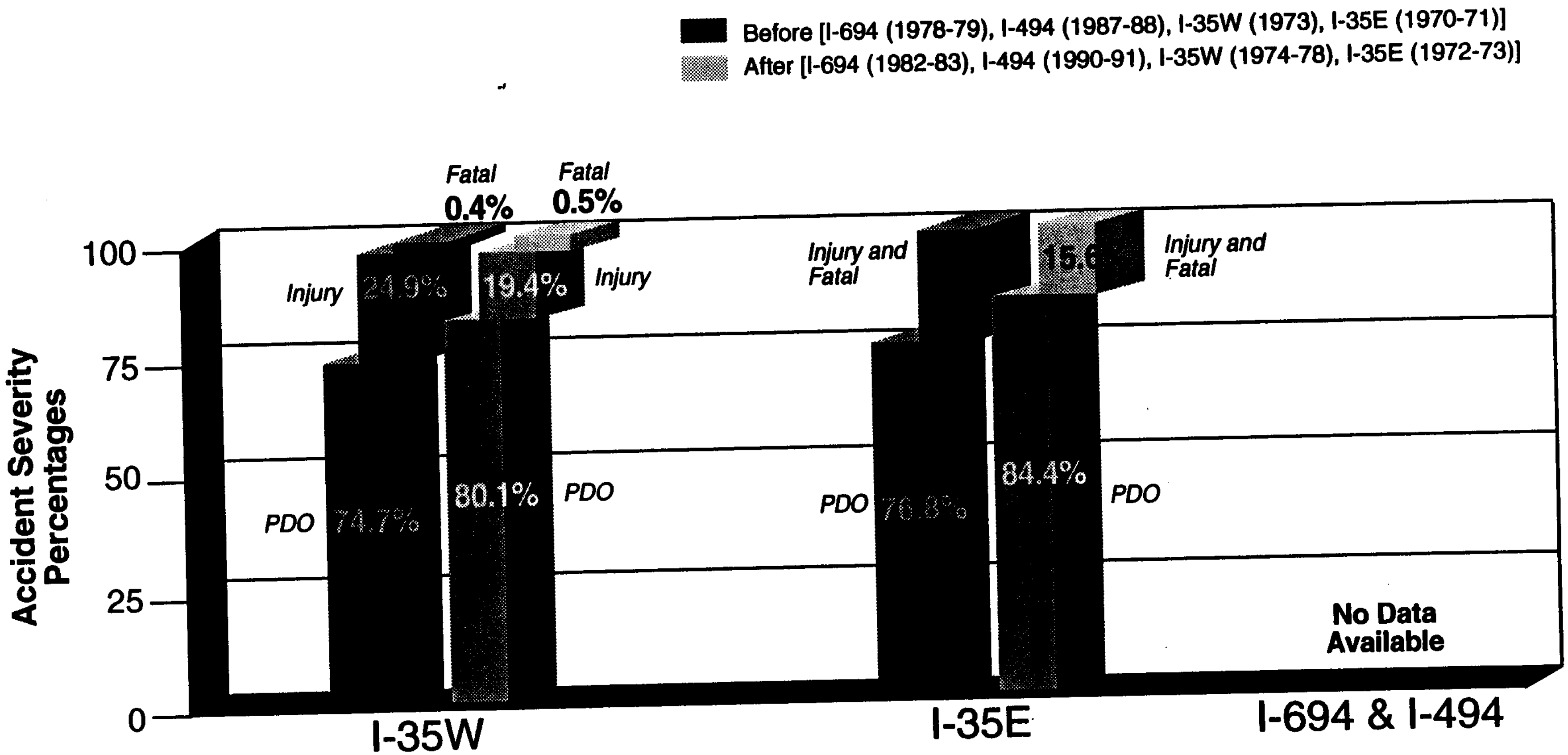
Long-Term Traffic Increases: Historical traffic data was analyzed to determine if the implementation of a TMS results in additional vehicle trips in that corridor (i.e. trips that would not have occurred if the TMS was not implemented). This analysis was conducted by comparing the total growth in regional travel over the past 20 years with the growth that occurred along one of the TMS freeways. The I-35W TMS was used for this analysis because it has been operational for the longest period of time and because historical traffic data was available.

The comparison of the growth in vehicle miles of travel (VMT) on I-35W before and after the implementation of a traffic management system to the VMT growth within the entire Minneapolis/St. Paul region is shown in figure 48. This data indicates that the VMT growth within the region increased by 92 percent from 1970 to 1990. This was greater than the respective 85 percent growth on I-35W from 1974 (system implementation) to 1994. Therefore, it was concluded that the implementation of a TMS does not necessarily result in additional vehicular travel along the affected freeway corridor.



Source: Mn/DOT Traffic Management Center

Figure 45. Annual average peak period accident type percentages before and after implementation of traffic management systems.



Source: Mn/DOT Traffic Management Center

Figure 46. Annual average peak period accident severity percentages before and after implementation of traffic management systems.

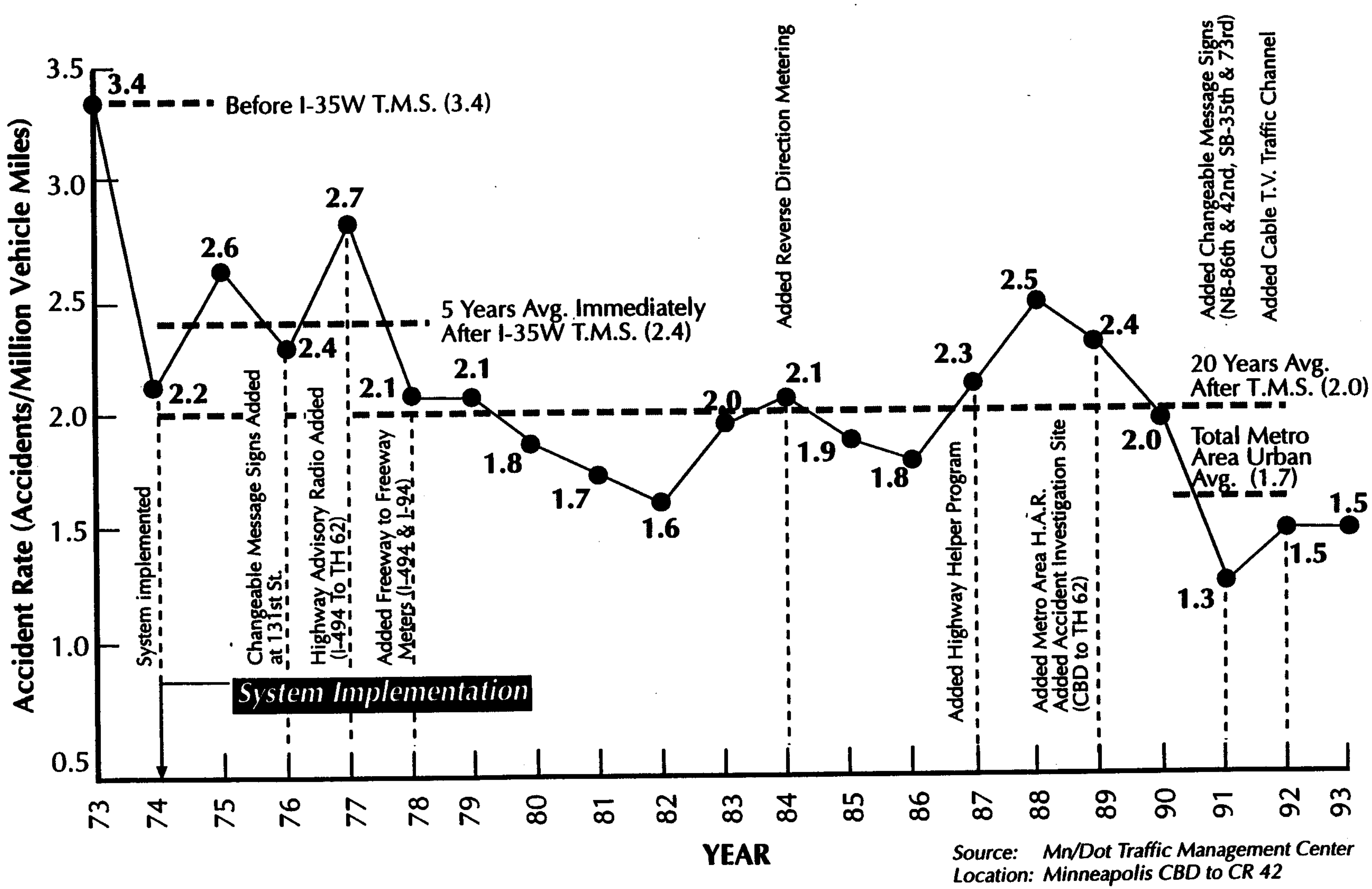


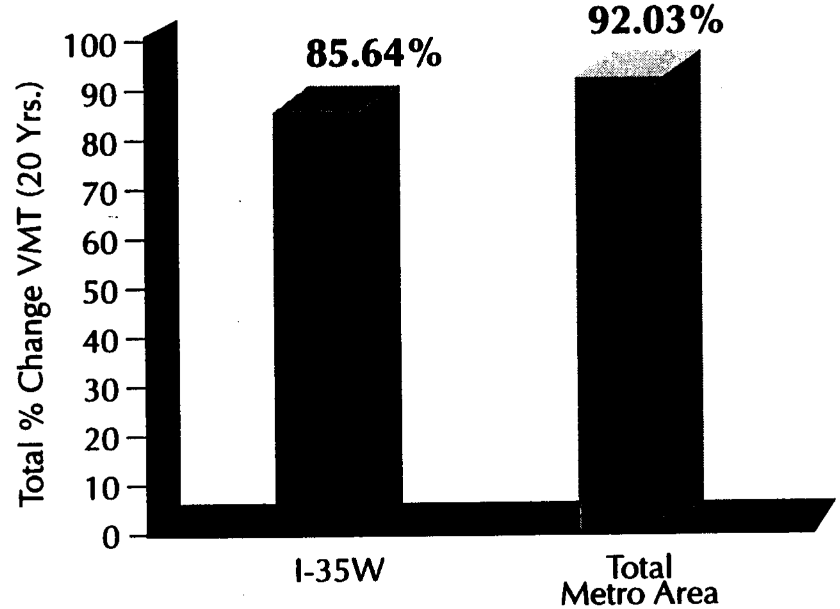
Figure 47. Peak period accident rates along I-35W before and after implementation of traffic management system.

Vehicle Miles of Travel (VMT) on I-35W

- 1973 to 1993 (20 Years)
- Increase of 57.49%
- Year of T.M.S. Implementation - 1974

VMT In Twin Cities Metro Area

- 1970 VMT - 26,400,000 vpd
- 1990 VMT - 50,695,500 vpd
- Increase of 92.03% (20 years)



Conclusion:

- 20 year Increase on I-35W Immediately Following T.M.S. Implementation is Less Than Similar 20 Year Increase on Regional System in Twin Cities Metro Area

Source: Mn/Dot Traffic Management Center Twin Cities Metropolitan Council.

Figure 48. Comparison of VMT growth on I-35W before and after the implementation of a traffic management system to metrowide VMT growth.

Trip Characteristics

The trip characteristics of vehicular travel in the region were recently documented in the 1990 *Travel Behavior Inventory* (TBI) prepared by the Metropolitan Council, the Metropolitan Planning Organization for the region. These characteristics were compared to the 1970 TBI findings. The following paragraphs describe the TBI findings for average trip length, duration and purpose.

<u>Trip Length</u>

The average trip lengths in 1970 and 1990 within the region are documented in figure 49. The data indicate that all vehicle trips have increased in length from 1970 to 1990 and that the average overall trip length in 1990 was 5.9 mi, an increase of approximately 20 percent over the comparable 1970 data.

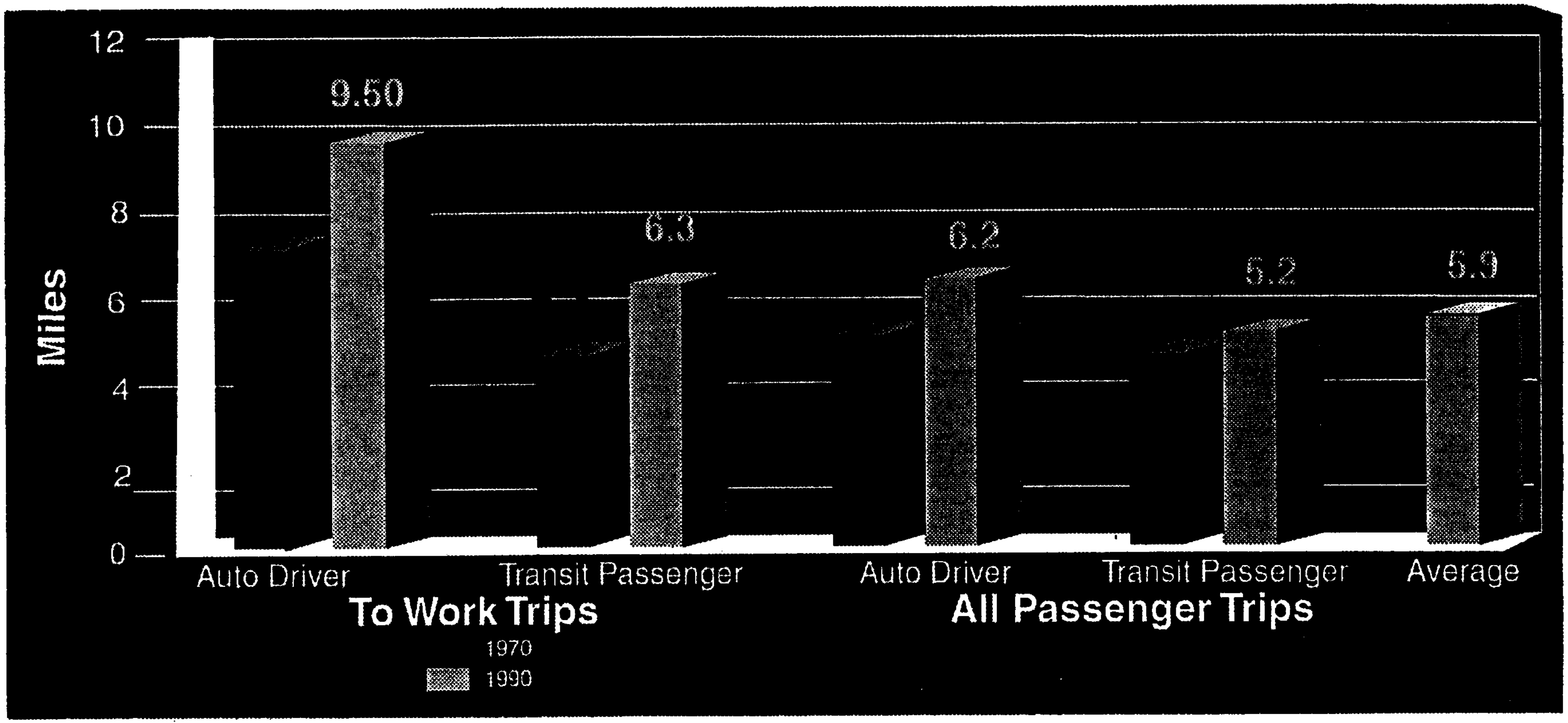
<u>Trip Duration</u>

The average trip duration in 1970 and 1990 within the region are shown in figure 50. The data indicate that the trip duration for auto driver work trips has increased from 1970 to 1990 but that all other trip travel times have decreased. For some trips, such as the non-work transit passenger, travel times decreased significantly. The average overall trip duration in 1990 was 15.8 minutes.

<u>Trip Purpose</u>

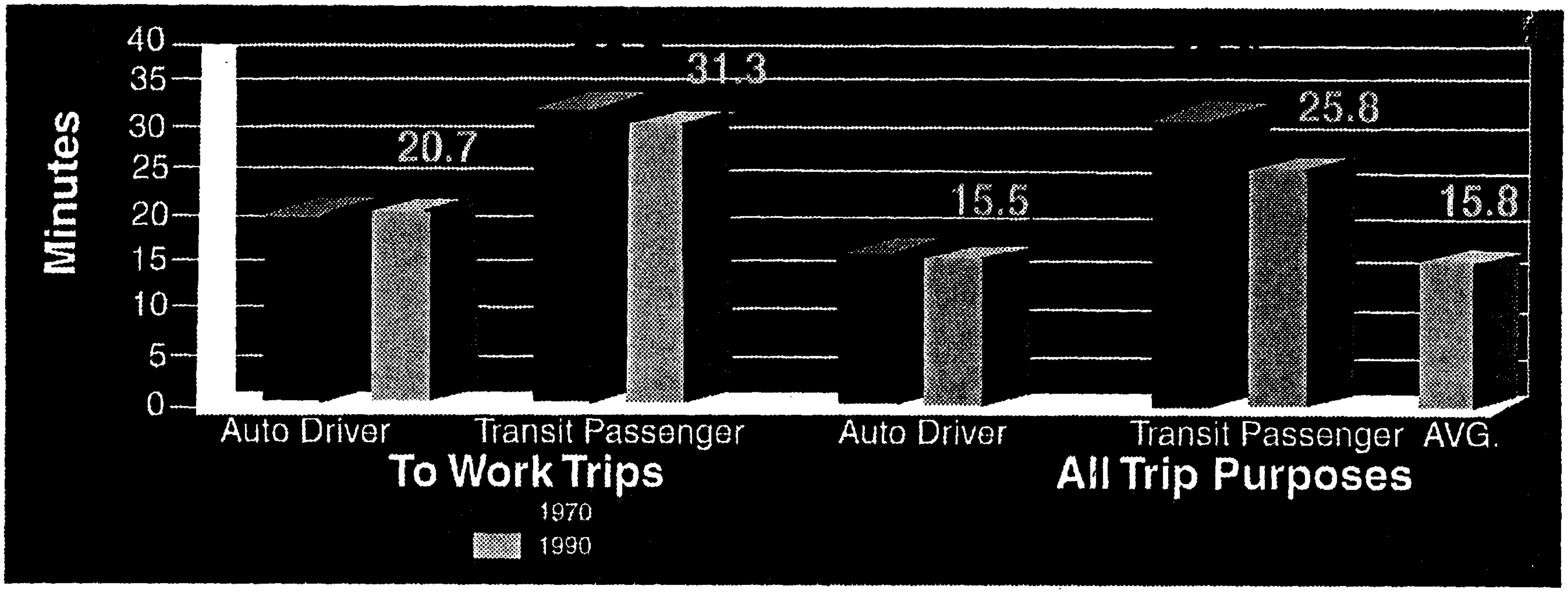
The purposes of vehicle trips in the region were determined and documented in the 1990 TBI. The data indicated the following trip purpose distribution:

- Home Based Other—36 percent.
- Non-Home Based Other—19 percent.
- Home Based Work—14 percent.
- Non-Home Based—14 percent.
- Home Based Shopping—12 percent.
- Home Based School—5 percent.



Source: Metro Council 1990 TBI TIMECOMP

Figure 49. Average trip length in Twin Cities metro area.



Source: Metro Council 1990 TBI TIMECOMP

Figure 50. Average trip duration in Twin Cities metro area.

OPPORTUNITIES/RISKS

The implementation of an automated highway system would have a large impact on traffic operations and safety in both urban and rural freeway environments. The results of the literature search, expert workshops, and the analysis of design and operational characteristics suggests that the deployment of an AHS would present opportunities to address the single most important transportation issue that was raised time and again during the course of this study—traffic safety. In addition, there also appear to be significant opportunities for improvement in travel efficiencies in urban areas.

There are, however, potential risks associated with deployment of an AHS, specifically in the area of uniformity and consistency of design. There are also potential risks in the areas of malfunction management, legal/tort liability, and human factors/driver acceptance; but these issues are beyond the scope of the urban/rural task.

A discussion of the key opportunities and risks in urban/fringe environments (these two areas were combined because of their similarities) and rural environments is presented in the following paragraphs. This is followed by a discussion of several items that have universal application.

Urban Environment

The implementation of AHS in an urban freeway environment can significantly reduce accidents, improve travel efficiency and air quality in the affected freeway corridor.

The three most common types of accidents occurring on urban freeways are rear end, sideswipe and single vehicle run off the road. Typically, rear end accidents account for more than 50 percent of all urban freeway accidents and these three particular types account for more than 85 percent of the accidents on Minnesota's urban freeways. These types of accident are also the types that are most susceptible to correction based on implementation of the kinds of lane keeping and collision avoidance technologies associated with RSC 2B.

Estimating the magnitude of the expected accident reduction associated with the deployment of an AHS is very speculative because it is a function of the specific features of the system and the extent of the deployment in a given area. However, it is reasonable to suggest that the minimum accident reduction should be similar to the reduction documented for existing freeway traffic management systems, since both systems perform similar surveillance, monitoring and control functions. Therefore, the documented 30 percent overall accident reduction associated with the freeway traffic management system implemented by the Minnesota Department of Transportation in the Minneapolis/St. Paul area appears to be a reasonable estimate of the future safety impact of a partially automated system with collision avoidance and lane following features in an urban environment. It should be noted that given the large number of accidents of the types susceptible to correction (85 percent) that the 30 percent reduction is probably a very conservative estimate and does not account for the potential effects of total automation. A totally automated system would likely result in a greater accident reduction because of the large number of urban freeway accidents caused by driver error. However, no existing data or studies were identified during the literature search that would provide support for quantifying the safety impact of a totally automated system.

A 30 percent reduction in urban freeway accidents associated with implementation of a partially automated AHS with lane keeping and collision avoidance features would result in eliminating approximately 860 accidents per year in Minnesota and roughly 52,000 accidents per year on a national basis (including over 100 fatal accidents). Based on typical costs for accidents ($2,000 for property damage only, $26,500 for personal injury and $500,000 for fatal) and the 30 percent accident reduction, the annual cost savings in Minnesota would be approximately $8 million and almost $475 million nationally.

Improvements in travel efficiencies are another area of opportunity for AHS. Continuing with the comparison to existing freeway traffic management systems, it appears reasonable to forecast 25 percent reductions in mainline vehicle delay and moderate increases in travel speed. It should be noted that these moderate increases in vehicle speed did not result in greater accident severity. On the contrary, the accident data indicated a 40 percent reduction in personal injury and fatal accidents after implementation of freeway traffic management.

In addition to the improved travel efficiency, the AHS can increase the overall capacity of urban freeways without the construction of additional travel lanes. The implementation of freeway traffic management, consisting of vehicle monitoring, surveillance and control, has increased the per lane capacity of urban freeways by approximately 10 to 15 percent and in one particular case by as much as 20 percent.

These documented improvements in safety, travel efficiency and freeway capacity were achieved at a construction cost of approximately $30 million spread over a 170-mi system, or an average per mile cost of about $175,000.

The key risk associated with implementation of AHS in an urban environment involves design consistency and the potential for violating drivers expectations. The single most important consideration in the design of roadways and traffic control devices is uniformity. Driving a motor vehicle is a learned skill based on the accumulated experience of a motorist. As a result, they have expectations for the road ahead based on what they have experienced in the past under similar circumstances. If the AHS includes design features that are new or just different from what is expected by the majority of the drivers based on their previous freeway experience, there is a large risk of driver error which could be difficult to overcome regardless of the amount of driver education or system control. Examples of unusual design and/or operational features include:

- Leftside entries or exits.
- Narrow lanes with small horizontal clearances to barriers.
- Weaving in/out of the inside through lanes.
- Possible queueing in transition lanes adjacent to through lanes (during check in).

- Different operating characteristics in different systems.

Another potential risk associated with AHS involves the need for and the present lack of interagency coordination. Currently, the monitoring and control associated with most freeway traffic management systems ends at the freeway ramp terminals. The control of the feeder and parallel arterials and the intersection traffic control devices is under the jurisdiction of a different unit of government. As a result, the operations of the freeway and arterial systems are hardly ever coordinated and often have different and competing objectives. In order to achieve system wide safety and travel efficiency improvements, the two systems and their corresponding units of government will have to work together in order to identify common goals, hardware and a coordinated operations plan. This means that one or both agencies will have to give up some control of at least a potion of their system and agree to compromise their own operating objectives. This could be a very difficult and time consuming process.

The risk associated with implementing an AHS on an urban freeway without this type of interagency coordination is the possibility of moving more vehicles at a faster rate along the freeway while at the same time creating increased congestion, delays and air quality problems at the key entrances to and exits from the freeway. Regarding the air quality issue, modeling has indicated that the increase in vehicle emissions associated with congestion on the feeder routes to the automated freeway could be as much as 300 percent greater than the expected decrease in emissions along the freeway attributed to the AHS.

Rural Environment

The implementation of an AHS in a rural freeway environment would likely have characteristics similar to RSC 4 (smart vehicle—passive highway) including lane keeping, collision avoidance and communication features. Deployment of this type of a system has the potential for addressing rural safety issues.

The two most common types of accidents along rural freeways include single vehicle run off the road and animal (specifically deer in Minnesota) hits. These types of accidents account for almost 60 percent of the total rural freeway accidents and the majority of the personal injury and fatal accidents. These types of accidents are also the types most susceptible to correction based on implementing the lane keeping and collision avoidance technologies associated with RSC 4.

Estimating the magnitude of the expected reduction in accidents in a rural freeway environment is more speculative, but no less important, than in the urban situation because there is no comparable rural freeway traffic management system to use as a model. In addition, any accident reduction would also be a dependant on the extent of the deployment of the system. However, an overall accident reduction of approximately 25 percent seems reasonable. This is based on achieving a 40 percent reduction in the 60 percent of the accidents involving vehicles running off the road and hitting deer. This reduction is probably conservative given the large number of accidents of the type susceptible to correction and, as with the urban environment, is the minimum expected reduction due to a partially automated system with collision avoidance and lane following features. A totally automated system would likely result in a greater accident reduction.

A 25 percent overall reduction in rural freeway accidents would result in the elimination of approximately 400 accidents (including four fatal) annually in Minnesota and almost 19,000 accidents (including 190 fatal) nationally. The annual cost savings associated with the 25 percent accident reduction (based on typical costs for property damage, personal injury and fatal accidents) amounts to approximately $5 million in Minnesota and $225 million nationally.

Addressing rural traffic safety issues and improving communication capabilities relative to the transmission of road and weather conditions and acquiring emergency services were identified as the two most important transportation related issues in rural Minnesota. Deployment of an AHS with the type of technologies associated with RSC 4 presents the opportunity to positively affect both of these issue areas.

The technological features of RSC 4, with the focus on the vehicle and only minimal investment in the roadway presents a significant opportunity to export the accident reduction benefits to the remaining 10,000 mi of rural state trunk highways and the tens of thousands of miles of rural county, township and forest roads in Minnesota. Approximately 33 percent of all accidents (30,000 in 1993) and almost 75 percent of the fatal accidents (447 in 1993) in Minnesota occurred on these types of rural roads. Even if an expanded AHS system could only cover a small fraction of these roads, the reduction in accident costs could be substantial.

Universal Safety Issues

Implementing AHS also presents two additional opportunities to address traffic safety issues. If any vehicle modifications also included mandatory seat belt usage and drunk driver lock out systems, the reduction in motor vehicle fatalities and the corresponding reduction in accident costs would be substantial. The National Highway Traffic Safety Administration (NHTSA)estimates that a modest 20 percent increase in seat belt usage and a four percent reduction in alcohol related crashes would save 2,900 lives and $250 million annually.

In addition, NHTSA has estimated that tax payers pick up the tab for approximately eight percent of the total cost of motor vehicle deaths, injuries and property damage. In 1990 this amounted to almost $11.4 billion, including $3.7 billion in public funds for health care, $1.6 billion in increased public assistance and $6.1 billion in lost tax revenues to the states and federal government. Given these figures, it is clear that improving highway safety can not only save lives but also tax dollars.

APPENDIX A

LITERATURE SEARCH ARTICLES

Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS — Technical Issues — Geometrics: No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfigratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Characteristics: Vehicle Classifctn	Physical Reqmts.
1	Fenton, R. and Mayhan, R. "Automated Highway Studies at the Ohio St. U.--An Overview" IEEE Transactions on Vehiclular Technology, Vol. 40, No. 1 February, 1991	have BRW 9/14/93										
2	Elias, J., et al "Practicality of Automated Highway Systems, Vol I: Summary Rpt" Report No. FHWA-RD-79-39 November, 1977	have BRW 9/22/93							U-4 U-2A F-4 F-2A			
3	Bender, J. "An Overview of Systems Studies of Automated Hwy Systems" IEEE Transactions on Vehicular Technology, Vol. 40, No. 1 February, 1991	have BRW 9/14/93	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4			U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4				
4	Tsao, H.S.J., Hall, R.W., Shladover, S.E., Plocher, T.A., Levitan, L. "Human Factors Dsgn of Atmtd Hwy Sys (AHS), 1st Gen.Scnrios" Working Paper on DTFH61-92-C-00100, FHWA 1993	have BRW 9/14/93				R-4 U-4	R-4 U-4					
5	Federal Highway Administration "Precursor Systems Analyses of Automated Highway Systems" FHWA RFP No. DTFH-61-93-R-00047 November, 1992	have BRW Battelle 3/1/93										
6	Bishop, J. R. "Status Report on the AHS Program" Presented at Autonomous Unmanned Veh. Soc. Ann. Mtg., June 28-30, 1993 in Washington, D.C.	have BRW 9/14/93										
7	"Supplemtry Descrptn of AHS (DRAFT)" FHWA distributed draft for AHS project September, 1993	have BRW 9/14/93										
8	Stevens, W. "The Automated Hwy System (AHS) Concepts Analysis (DRAFT)" MITRE Tech. Rep. MTR 93W0000123, McLean, VA August, 1993	have BRW Aug-93								2		2
9	"IVHS Strategic Plan -- Report to Congress" U.S. Dept. of Transportation December, 1992	have BRW 8/1/93										
10	Shladover, S.E., et al. "Automatic Veh. Control Developments in the PATH Program" IEEE Transactions on Vehicular Technlgy, Vol. 40, No. 1, N.Y. February, 1991	have BRW 9/14/93			U-2							

U,F,R = Urban, Fringe, or Rural Setting; Numbers refer to applicable RSC(s)

Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS — Technical Issues — Geometrics: No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfgratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Characteristics: Vehicle Classifctn	Physical Reqmts.
11	Fenton, R., Mayhan, R., et al. "Fundamental Studies in Automatic Vehicle Control" Rep. No. FHWA/RD-80/198, The Ohio St. U. August, 1981	have BRW 9/22/93 Mfiche Ex.Sum			U-1 R-1	U-1 R-1						
12	Bender, J.G., Bonderson, L.S., et al. "System Studies of Automated Highway Systems - Final Report" Rep. No. FHWA/RD-82-003, GMotors Transp. Sys. Ctr., Warren,MI August, 1981	have BRW 9/22/93 Mfiche Ex.Sum	U-1 R-1 U-4 R-4	U-1 R-1 U-4 R-4			U-1 R-1 U-4 R-4	U-1 R-1 U-4 R-4				
13	Chang, K.S., Hedrick, Zhang, Varaiya, Tomizuka, and Shladover "Automated Hwy Sys Experiments in the PATH Program" IVHS Journal, Vol. 1(1), pp. 63-87 1993	have BRW 9/14/93										
14	Chang, K.S., et al. "Experimentation with a Veh. Platoon Control System" Veh. Navgtn & Info. Sys Conf., Paper No. 912868 Dearborn, MI 1991	have BRW 9/22/93				U-2 R-2						
15	Smith, Dirk E., and Starkey, John M. "Overview of Veh. Modls, Dynmics, & Cntrl Appl'd to Automtd Veh." Advanced Automotive Technologies, Winter Ann. Mtg. ASME December, 1991	have BRW 10/4/93										
16	Bresnock, A., Miller, M., Lechner, E. "Hwy Automation: System Modeling for Impacts Analysis" Veh. Navgtn & Info Sys. Conf. Procdgs, Dearborn, MI October 20-23, 1991	have BRW 9/22/93	U-2A	U-2A								
17	Niehaus, Axel and Stengel, Robert F. "Probability-Based Decision Making for Atm'd Hwy Driving" Veh. Navgtn & Info Sys. Conf. Procdgs, Dearborn, MI Pt. 2, SAE October 20-23, 1991, (#912869)	have BRW 9/22/93										
18	Lafortune, S., Sengupta, R., Kaufman, D., & Smith, R. "A Dynamical Sys. Model for Traffic Assignment in Networks" Veh. Navgtn & Info Sys. Conf. Procdgs, Dearborn, MI Pt. 2, SAE October 20-23, 1991, (#912869)	have BRW 9/22/93										
19	Johnston, R.A., DeLuchi, M.A., Sperling, D. and Craig, P.P. "Automating Urban Freeways: Policy Research Agenda" J. of Transp. Eng. Vol. 116 No. 4, ASCE July 1, 1990	have BRW 10/4/93	U-4	U-4	U-4	U-4						
20	Anwar, Mohammed and Jovanis, Paul "Assessing the Safety Benefits of Automated Freeways" for PATH, U. Ca. Davis, UCB-ITS-PRR-93-29 December, 1993	Have BRW 5/18/94	U-2B									

U,F,R = Urban, Fringe, or Rural Setting; Numbers refer to applicable RSC(s)

Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS — Technical Issues — Geometrics: No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfgratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Characteristics: Vehicle Classifctn	Physical Reqmts.
21	Deakin, Elizabeth A. "Opportunities and Constraints for Ad. Hwy. Technlgies: A Speculitiv PATH, U. Ca. Berkeley, UCB-ITS-PRR-89-7 October, 1989	Have BRW 5/18/94										
22	Hall, Randolph W. and Kamoun, Mahdi "Evaluation of Highway Bottlenecks" PATH, U. Ca. Berkeley, UCB-ITS-PRR-91-9 July, 1991	Have BRW 5/18/94										
23	Varaiya, Pravin and Shladover, Steven E. "Sketch of an IVHS Systems Architecture" PATH, U. Ca. Berkeley, UCB-ITS-PRR-91-3 February, 1991	Have BRW 5/18/94										
24	McMahon, Donn H. and Hedrick, Karl J. "Longitudinal Model Development for Automated Roadway Vehicles" PATH, U. Ca. Berkeley, UCB-ITS-PRR-89-5 October, 1989	Have BRW 5/18/94										
25	Eskafi, Farokh; Khorramabadi, Delnaz, and Varaiya, Pravin "SmartPath: An Automated Highway System Simulator" PATH, U. Ca. Berkeley, Tech. Memo. 92-3 23-Oct-92	Have BRW 5/18/94				U-2A TWO LANES						
26	Varaiya, Pravin "Smart Cars on Smart Roads: Problems of Control" PATH, U. Ca. Berkeley, Tech. Memo. 91-5 December, 1991	Have BRW 5/18/94										
27	Shladover, Steven E. "Potential Contributions of IVHS to Reducing Transportation's Greenl PATH, U. Ca. Berkeley, Tech. Memo. 91-4 August, 1991	Have BRW 5/18/94										
28	Rockwell International Science Center "Potential Payoffs from IVHS: A Framework for Analysis" PATH, U. Ca. Berkeley, UCB-ITS-PRR-92-7 August, 1992	Have BRW 5/18/94										
29	Hall, Randolph W. "Time Benefits of New Transportation Technologies: The Case of Hig PATH, U. Ca. Berkeley, UCB-ITS-PWP-91-4 June, 1991	Have BRW 5/18/94	U-2	U-2		U-2		U-2				
30	Scapinakis, Dimitris A. and Garrison, William L. "Communications and Positioning Systems in the Motor Carrier Indus PATH, U. Ca. Berkeley, UCB-ITS-PRR-91-10 1991	Have BRW 5/18/94										

U,F,R = Urban, Fringe, or Rural Setting; Numbers refer to applicable RSC(s)

ACTIVITY AREA A: URBAN AND RURAL ANALYSIS

Pub. No.	Author/Publication	BRW Status	Technical Issues: Geometrics: No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfgratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Characteristics: Vehicle Classifctn	Physical Reqmts.
31	Ritchie, Stephen G. and Cheu, Ruey L. "Neural Network Models for Automated Detection on Non-Recurring (PATH, U. Ca. Berkeley, UCB-ITS-PRR-93-5 June, 1993	Have BRW 5/18/94										
32	Polydoros, Andreas "Vehicle to Roadside Communications Study" PATH, U. Ca. Berkeley, UCB-ITS-PRR-93-4 June, 1993	Have BRW 5/18/94										
33	Hsu, Ivy Pen-Shan and Walrand, Jean "Communication Requirements and Network Design for IVHS" PATH, U. Ca. Berkeley, UCB-ITS-PWP-93-18 November, 1993	Have BRW 5/18/94										
34	Varaiya, P. and Slhadover, S. "Sketch of an IVHS Systems Architecture" I. of T. S., Rep. UCB-ITS-PRR-91-3 PATH, U.Cal-Berkeley October, 1990 rev'd Feb, 1991	abstract only										
35	Miller, M., Bresnock, A., Lechner, E., & Shladover "Hwy Automation: Regional Mobility Impacts Assessment" TRB 72nd Annual Mtg, Washington, D.C. Paper No. 930522 January 10-14, 1993	abstract only										
36	Gardes, Y., Lunsford, M., May, A., and Van Aerd, M. "Applctn of the Intratn Model to Demonstrate Simulation of ATIS" TRB 72nd Annual Meeting, Washington, D.C. Paper No. 930474 January 10-14, 1993	abstract only										
37	Rao, B., Varaiya, P., and Eskafi, F. "Invstgatns into Achvble Capcties and Stream Stblity w/ Coord. I.V." TRB 72nd Annual Meeting, Washington, D.C. Paper No. 930803 January 10-14, 1993, (November 27, 1992)	abstract only										
38	Rao, B., and Varaiya, P. "Flow Bnfits of Autnmous Intel. C. Cntrl in Mixed Man. & Automtd Tra TRB 72nd Annual Meeting, Washington, D.C. Paper No. 930616 January 10-14, 1993, (November 27, 1992)	abstract only										
39	Syverud, Kent D. "Smrt Car and Smrt. Hwy Liability: Lessons from Experience w/ ... U. of MI Transp. Res. Institute, Ann Arbor, MI 1992	abstract only										
40	Farber, Eugene I. of Ford Motor Corp. "Human Factors Issues in IVHS" Prceedngs 1992 Intrntl Cngress on Trnptn Electronics: Cvrgce SAE 1992	abstract only										

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Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS									
			Technical Issues									
			Geometrics								Vehicle Characteristics	
			No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfgratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Classifctn	Physical Reqmts.
41	Elias, J., Stuart, K., Sweet, L., and Kornhauser. A. "Prcticality of AHS, Vol. II, Technical Design Considerations" Calspan Corp. FHWA Office of R & D, Springfield, VA January, 1977	abstract only										
42	Johnston, Robert A. and Page, Dorriah L. "A Prelimnry Systems-level Eval. of Automated Urban Freeways" Applctns of Ad. Techs. in Trnptn. Eng. Procdgs 2nd Intntl Conf., MSP. MN August 21, 1991	abstract only										
43	Underwood, S.E. "Societal and Institutional Considerations in IVHS" IVHS: Technology and Socioeconomic Aspects (SP-833), U. of MI January, 1990	abstract only										
44	Okuno, Akihiro, Kutami, Atsushi, and Fujita, Kenji "Toward Automomous Criusing on Highways (#901484)" IVHS: Technology and Socioeconomic Aspects SAE January, 1990	abstract only										
45	Garrison, William L. "Assessment of New Technologies for Highway Operations" Inst. of Transp. Studies, U. of Cal.-Berkeley January, 1988	abstract only										
46	Toye, CR "Automated Guideway Network Traffic Modeling" Transp. Systems Cntr, 55 Broadway, Cambridge, MA 1972	abstract only										
47	Skinner, S.K. Opening Gen. Session Remarks of Skinner AASHTO Proceedings 1989, pg. 7-14	abstract only										
48	David, Y. "Interest, Feasibility & Perspectives of Automated Hwys" 3rd Intl Conf. Veh. Nav. & Info. Sys. (VNIS '92), Oslo, Norway 1992	abstract only										
49	Johnston, Robert A., and Page, Dorriah L. "A Prelim. Systems-Level Evaluation of Automated Urban Frwys" Applctns of Ad. Techs. in T. Eng.: Proc. of 2nd Intl Conf. Minnapls. August 21, 1991, ASCE	abstract only										
50	Griswold, Norman "Autonomous Vehicle - Constrained Test and Evaluation" Texas Transportation Institute, Texas DOT January 11, 1991	abstract only										

U,F,R = Urban, Fringe, or Rural Setting; Numbers refer to applicable RSC(s)

Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS — Technical Issues — Geometrics								Vehicle Characteristics	
			No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfgratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Classifctn	Physical Reqmts.
51	U.S. General Accounting Office "Traffic Congestion: Federal Effort to Improve Mobility" Rep. to Chairman, Subcommittee on T. & Rel. Agencies. U.S. Senate December, 1989	abstract only										
52	Lomax, Timothy J., Bullard, Diane L., & Hanks, James W. "Impact of Declining Mobility in Major Texas and Other U.S. Cities" Texas Transportation Institute, Texas A&M University September, 1988	abstract only										
53	Leasure, William A. "The Importance of Crash Prob. Anal. in Def. NHTSA's IVHS Prg." IVHS America 2nd Ann. Mtg., Newport Beach, CA May 17-20, 1992	abstract only										
54	Komoda, N., Suzuki, T., and Shigematsu, T. et al. (Toyota M. Co.) "Cooperative Veh./Hwy System for Automated Vehicle" IVHS America 2nd Ann. Mtg., Newport Beach, CA May 17-20, 1992	abstract only										
55	Endo, Goro and Janoyan, Verej "Santa Monica Freeway Smart Corridor Project" Compendium of Tech. Papers, ITE Dist. 6 Ann. Mtg. June 20, 1991	abstract only										
56	Beubien, Richard "ATMS: Seven Steps to Deployment" IVHS America January, 1992	abstract only										
57	Turrentine, T., Sperling, D., and Hungerford, D. "Consumer Accptnce of Adptive Cruise Cntrl & Coll. Avoidnc. Systen TRR N1318 pp. 118-121 January, 1991	abstract only										
58	Hosaka, Akio and Taniguchi, Masaaki "The Devlpmt on Advncd Veh. Cntrl Technlogies for Autnmous Drivin TRB, 71st Annual Meeting, Washington, D.C. (#920309) January 12-16, 1992	abstract only										
59	Taniguchi, Masaaki, Hosaka, Akio, and Kurami, Kunihiko "Dvlpmt of Automomously Controlled Vehicle, PVS" NVIS Conf. Proceedings, Dearbom, MI Part 2, SAE (#912870) October 20-23, 1991	abstract only										
60	Frank, A.A., Liu, S.J. and Liange, S.C. "Longitdnl Cntrl Cncpts for Atm'd Automtd automobiles & Trucks Ope Vehicle/Highway Automation; Technology & Policy Issues. SAE Sp-791 January, 1989	abstract only										

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61	ITE IVHS European Study Tour: Participants' Report Institute of Transportation Engineers, Washington, D.C. January, 1992	abstract only										
62	Shladover, S.E. "Roadway Electrification and Automated Technologies" J.of Transportation Engineering Vol. 116 No. 4 ASCE June, 1990	abstract only										
63	Andre, M., Hickman, A.,J. and Hassel, D. "Op. Chrctrstcs of Cars in Urban Areas & their Inflnce on Exhst Emis Advanced Telematics in Road Transport, Proc. DRIVE Conf. Brussels February 4-6, 1991 V.II Elsevier	abstract only										
64	Gordon, Deborah "IVHS: An Environmental Perspective" IVHS Policy: Wkshp on Institutional and Envirnmtl Iss., Asilomar Conf. April 26, 1992, Monterey, CA	abstract only										
65	McGurrin, Micheael F. and Wang, Paul T.R. "Object-Oriented Traffic Simulation with IVHS Applications" VNIS Conf Proc Dearborn, MI October 20-23, 1991	abstract only										
66	Fearnsides, J.J., and McGurrin, M.F. "A Vehicular Traffic Anal. Capability for IVHS Engineering" 24th ISATA Itntl Symp. on Automotive Tech. and Atmtn, Florence, Italy May 20-24, 1991	abstract only										
67	Brecher, Aviva and Ritter, Gary "Institutional and Environmental Issues: Lessons from Other Technlg IVHS Policy: Wkshp on Institutional and Envirnmtl Iss., Asilomar Conf. April 26, 1992, Monterey, CA	abstract only										
68	Contatino, J. "IVHS: The Path to Mobility" AASHTO Quarterly Mag. Vol. 70, No. 3 pp 5, 7 July, 1991	abstract only										
69	Tarnoff, Philip (Farradyne Systems Inc.) "Ecnmc Issues Assoc'd w/ Def. of Public/Private Roles in Dplymt of I Public & Private Sector Roles in IVHS Deployment; Sem. Rockville, MD April 8, 1992 U.S. DOT, FHWA	abstract only										
70	Suorsa, R.E.; Sridhar, B. Parallel Implementation of a Multisensor Feature-Based Range-Estim Corp. Source Codes: 019045001; NC473657 33970	Abstract only										

U,F,R = Urban, Fringe, or Rural Setting; Numbers refer to applicable RSC(s)

Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS — Technical Issues — Geometrics: No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfigratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Characteristics: Vehicle Classifctn	Physical Reqmts.
71	Del Bimbo, A.; Landi, L.; Santini, S. Determination of Road Irections Using Feedback Neural Nets Journal: Signal Processing vol. 32, No. 1-2, p. 147-60 34090	Abstract only										
72	Reece, D.A.; Shafer, S.A. A Computational Model of Driving for Autonomous Vehicles Journal: Transportation Research, Part A (Policy and Practice) vol. 27A, no. 1, p. 23-50 33970	Abstract only										
73	Gothard, Benny; Spomer, R.L.; Medina, J.; Chun, Wedell H. Design Issues with the SSV Platform Proceedings of SPIE - The International Society for Optical Engineering v. 1831 1993	Abstract only										
74	Jou, Chi-Cheng; Wang, Nan-Ching Training a Fuzzy Controller to Back Up an Autonomous Vehicle Conference Title: Proceedings of the IEEE International Conference on Robotics and Automation 1993	Abstract only										
75	Freisleben, Bernd; Kunkelmann, Thomas Combining Fuzzy Logic and Neural Networks to Control an Autonom 1993 IEEE International Conference on Fuzzy Systems Second IEEE Int. Conf. Syst 1993 1993	Abstract only										
76	Hartmann, Klaus; Weber, Juergen Multivision System for 3-D Measurement within Camera Vision Proceedings of SPIE - The International Society for Optical Engineering v. 1828 1993	Abstract only										
77	Burt, Peter J.; Anandan, P.; Hanna, Keith Electronic Front-End Processor for Active Vision Proceedings of SPIE - The International Society for Optical Engineering v 1825 1993	Abstract only										
78	Ross, H.R. Smart Cars Journal: Earthword: A Journal of Environmental and Social Responsibility Issue Number 4, pg. 72 920000 1992	Abstract only										
79	Cheslow, M. Estimates for 2000 and 2010 Source: IVHS America 920000 1992	Abstract only										
80	Klein, H.K. The Design of an Organizational Framework for Cooperation in IVHS Source: IVHS America 920000 1992	Abstract only										

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Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS — Technical Issues — Geometrics: No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfgratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Characteristics: Vehicle Classifctn	Physical Reqmts.
81	Tsugawa, S. Concept of Super Smart Vehicle Systems and Their Relation to Adva Journal: Transportation Resource Board Issue Number 1358, pg. 42-49 920000 1992	Abstract only										
82	Tsugawa, S.; Wantanabe, N.; Fujii, H.; Hirayama, M. Research and Development Projects for Info-Mobility Technologies Source: IVHS America 920000 1992	Abstract only										
83	Santiago, A.J.; Chen, H. Traffic Modelling Needs for Advanced Traffic Management Systems (Source: Organization for Economic Cooperation and Devel 1991	Abstract only										
84	Smart Highways: An Assessment of Their Potential to Improve Trave Report Number: GAO/PEMD-91-18 1991	Abstract only										
85	Major Programs and Demonstrations Journal: IEEE Transactions on Vehicular Technology Vol: 40, Issue Number 1, pg. 131-158 1991	Abstract only										
86	Sobey, A.J. Business View of Smart Vehicle-Highway Control Systems Journal of Transportation Engineering Vol: 116, Issue Number 4, pg. 461-478 1990	Abstract only										
87	Pue, A.J.; Chiu, H.Y.; Brown, S.J., Jr. Operational Concepts and Implementation Techniques for Vehicle-Fo Source: John Hopkins University, Final Report: UMTA-MD-06-0038-79-1 1979	Abstract only										
88	Patel, R.K. Role of IVHS Engineer in Urban Environment Institute of Transportation Engineers 1993	Abstract only										
89	Shladover, S.E. Research and Development Needs for Advanced Vehicle Control Sys Journal: IEEE Micro Vol.13, No. 1 34001	Abstract only										
90	Kene, Surender K.; Bajpayee, Shivendra LaneLok: Robust Line and Curve Fitting of Lane Boundaries Proceedings of SPIE - The International Society for Optical Engineering V 1831 1993	Abstract only										

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Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS — Technical Issues — Geometrics: No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfigratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Characteristics: Vehicle Classifctn	Physical Reqmts.
91	Bishop, Richard J., Jr.; Juberts, M.; Raviv, D. Autonomous Vision-Based Technology for AVCS IEEE Vehicular Technology Conference 1993	Abstract only										
92	Schreiber, Randal A.; Noe, Philip S. Self-Correcting Differential Global Positioning System Proccedings of the National Technical Meeting, Institute of Navigation 1993	Abstract only										
93	Brown, W. Smart Highways Journal: Transportation Builder, Vol: 1, Issue Number 1, pg. 24-25 1989	Abstract only										
94	Shladover, S.E. "Issues in Communication Standardization for Advanced Vehicle Cor TRR 1324 pp 8-10 1991	Abstract only										
95	Sweeney, L.E. Jr., and Zavoli, W.B. Microcomputers in Transportation. Trends in Digital Road Map Data I ASCE, New York, NY pp 257-67 1993	Abstract only										
96	Fisher, R.J. Smart Travelers of the 1990s ITE Journal Vol 61, Issue 1 pp 17-19 1991	Abstract only										
97	Rogers, E.M. "Life is in the Ballance. Weighing the Questions of Risks and Benefit Dow Chem. USA, Health and Env. Sciences, Midland, MI Rpt. HS-039 419 1985	Abstract only										
98	Chui, M.K., McFarland, W.F. "The Value of Travel Time: New Estimates Developed Using a Speed TTI, Texas A&M U. College Station, TX Rpt. FHWA/TX-86/33-396-2F 1986	Abstract only										
99	Johnston, A.R., Nelson, M, Cassell, P., Herridge, J.T. "AMTV Headway Sensor and Safety Design" Jet Propulsion Labtry, UMTA Rpt. UMTA-CA-06-0088-80-1 Final Rpt. 1980	Abstract only										
100	Jondrow, J, Bowes, M, Levy, R. "Optimum Speed Limit. Revised" Public Research Institute Rpt. PRI-PP-312-REV Alexandria, VA Jul-83	Abstract only										

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Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS — Technical Issues — Geometrics: No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfigratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Characteristics: Vehicle Classifctn	Physical Reqmts.
101	Murata, S., Hirose, T. "Dead Reckoning of an Automated Guided Vehicle by Differential Od J. of Mechanical Eng. Labrty. Vol. 47, no. 1 pp 1-9 Jan, 1993	Abstract only										
102	Pilutti, T. Raschke, U. , Koren, Y. "Computerized Defensive Driving Rules for Highway Manuevers" Proc. of 1990 Am Control Conf. pp 809-11 Vol. 1 (IEEE Cat. No. 90CH2896-9) 1990	Abstract only										
103	Graefe, Volker; Jacobs, Ute "Detection of Passing Vehicles by a Robot Car Driver" Proc 91 IEEE RSJ Int Workshop Intell Robots Syst IROS 91 1992	Abstract only										
104	Tsugawa, S.; Murata, S.; Yatabe, Teruo; Hirose, T. "Vehicle Following System Using Vehicle to Vehicle Communication" Proc USA-Japan Symp on Flexible Automations, Minneapolis, Mn 1988	Abstract only										
105	Mammano, F. and Bishop, J.R. "Status of IVHS Technical Developments in the U.S." Proceedings of 1992 IEEE Vehicular Technology Society Conf. May, 1992	title only										
106	Federal Highway Administration "Intelligent Vehicle-Highway Systems: A Public/Private Prtnrshp" Report October, 1991	title only										
107	"Radar for Buses" The Institute, pp. 4-5 July/August, 1992	title only										
108	"Cadillac to Try Radar on Cars" Automotive News, pg. 35 June 15, 1992	title only										
109	Bishop, J.R. "Intelligent Travel: The Automated Highway System" Proceedings on the 1993 Intelligent Automomous Sys. Conf. February, 1993	title only										
110	"Intermodal Surface Transportation Act of 1991" Public Law 102-240 December 18, 1991	title only										

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Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS — Technical Issues — Geometrics								Vehicle Characteristics	
			No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfgratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Classifctn	Physical Reqmts.
111	"Invitation for Proposals for AHS Implementation (DRAFT)" U.S. Dept. of Transportation	title only										
112	Rao, B., et. al. "Invstgtns into Achvble Capacities and Stream Stblity w/ Coord.I.V." Paper No. 930803, TRB 70th Annual Mtg, Washington, D.C. January, 1993	title only										
113	"Human Factors Design of AHS" RFP, DTFH61-92-R-00100 June, 1992 -- contract award, September, 1992	title only										
114	Stevens, W. "Precursor Systems Analyses for the AHS Program" Working Paper WP 92W0000382, MITRE Corp., McLean, VA November, 1992	title only										
115	"Broad Agency Announcemt for Precursor Sys. for AHS Prog." U.S. Dept. of Transportation November, 1992	title only										
116	Bender, J. "System Studies of Automated Highway Systems" EP-81041A-1, General Motors Technical Center, Warren, MI August, 1981	title only										
117	Wilson, D.G., et al. "Quadramode Transport: A Class of Controlled Systems" dist'd @ Industrial Liaison Symposm on Urban Transp. May, 1971	title only										
118	Shladover, S. "Potential Freeway Capacity Effects of Advncd Veh. Control Sys." Applications of Ad. Technlgys in Tranp. Eng., Minneapolis August, 1991	title only										
119	Chang, K.S., et al. "A Preliminary Implementation for Veh. Platoon Control System" Proceedings, American Control Conf., Boston, MA 3078-3083 1991	title only										
120	Hedrick, J.K. et al. "Longitudinal Veh. Controller Design for IVHS Systems" Proceedngs, American Control Conf., Boston, MA 3107-3112 1991	title only										

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Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS									
			Technical Issues									
			Geometrics								Vehicle Characteristics	
			No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfgratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Classifctn	Physical Reqmts.
121	Hessburg, T. et al. "An Experimental Study on Lateral Control of a Vehicle" Proceedngs, American Control Conf., Boston, MA 1991	title only										
122	McMahon, D.H., Hedrick, J.K., and Shladover, S.E. "Veh. Modeling and Control for Automated Hwy Systems" Proceedngs, American Control Conf., San Diego, CA 297-303 1990	title only										
123	McMahon, D.H. et al. "Longitudinal Vehicle Controllers for IVHS: Theory and Exprimt" Proceedngs, American Control Conf., Chicago, IL 1753-1757 1992	title only										
124	Parsons, R. and Zhang, W.-B. "PATH Lateral Guidance System Requirements Definition" Proceedings, 1st Intrnatnl Conf. on Applctn of Adv. Tech. in TE 1990, San Diego, CA 275-280	title only										
125	Peng, H. and Tomizuka, M. "Lateral Control of Front-Wheel-Steering Rubber-Tire Vehicles" Inst. of T. Studies, U. of Cal-Berk. PATH Rep. UCB-ITS-PRR-90-5 1990	title only										
126	Porshe, I.R. et al. "Real-Time Task Mngr for Commctns & Cntrl in Multi-car Platoons" Intelligent Vehicles Conference, Detroit, MI 1992	title only										
127	Shladover, S.E. "Longitudinal Cntrl of Automtd Guideway Transit Veh. w/i Platoons" J. of Dynamic Systems, Measuerement and Control, 100, 302-310 1978	title only										
128	various authors Proceedings of Am. Control Conference Veh. Control, AHS, etc. 1990, 1991, 1992, 1993 (if possible)	title only										
129	Niehaus, Axel and Stengel, Robert F. "An Expert System for Automated Highway Driving" Proceedings of Am. Control Conference, pp. 274-80 1991	Title only										
130	Traffic Modeling Software for IVHS Applications 04030912 INSPEC Abstract Number: C9201-7440-013	Title only										

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Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS									
			Technical Issues								Vehicle Characteristics	
			Geometrics									
			No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfgratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Classifctn	Physical Reqmts.
131	Visual Obstacle Detection for Automatically Guided Vehicles 03863714 INSPEC Abstract Number: C91031883	Title only										
132	Design of an Automatic Guided Vehicle Stystem 03328281 INSPEC Abstract Number: C89018337	Title only										
133	Simulating a System of Automatically Guided Vehicles 02605748 INSPEC Abstract Number: C86015557	Title only										
134	'Smart' Highway Joint Venture Formed by Lockheed and AT&T Traffic World 920000 1992	Title only										
135	Heinz, Zackor Preconditions of the Introduction of Smart Cars and Roads Journal: Proceedings 920000 1992	Title only										
136	Fontaine, Helene; Gilles Malaterre; Malaterre, Gilles The Smart Car and Traffic Safety Journal: Transport, Environment, Circulation 920000 1992	Title only										
137	Tsugawa, S.; Wantanabe, N.; Fujii, H. Super Smart Vehicles System: Its Concept and Preliminary Works Journal: Vehicle Navigation and Information Systems, pg. 269-277 1991	Title only										
138	Smart Trucks, Smart Highways Journal: Fleet Owner, Vol: 85, Issue Number 8; pg. 50-76 1990	Title only										
139	Camera-Controlled Vehicles as a Step Towards the 'Smart Car' Source: Bundesministerium fuer Forschung und Technologie, Report Number: NP-9770286 1988	Title only										
140	Eric C. Huber ... Et AL; Huber, Eric C. Computer Simulation and Animation of a Highway Driving Environme Transportation Research Board 1993	Title only										

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Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS									
			Technical Issues									
			Geometrics								Vehicle Characteristics	
			No. of Lanes	Lane Width	Intrchg. Cnfigratn	Intrchg. Spacing	Median Cnfigratn	ROW	Curvature	AHS/RSC Inf. Desgn	Vehicle Classifctn	Physical Reqmts.
141	B.S.Y. Rao, P. Variaya; F. eskafi; Varaiya, P. P.; Eskafi, F Investigation into Achievable Capacities and Stream Stability with Co Transportation Rsearch Board 1993	Title only										
142	Shladover, SE Potential Contributions of Intelligent Vehicle/Highway Systems (IVHS American Society of Civil Engineers 1993	Title only										
143	Improving Automated Storage/Retrieval System Performance Throug INSPEC Abstract Number: C91073440	Title only										
144	The Perception of Moving Vehicles, Progress Report V - Thresholds Transport and Road Research Laboratory	Title only										
145	Mobile Robot Vehicles for Physical Security NTIS Accession Number: DE87010514/XAB	Title only										
146	Advanced Technology Mobile Robotics Vehicle Fleet NTIS Accession Number: DE87007526/XAB	Title only										
147												

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ACTIVITY AREA A: URBAN AND RURAL ANALYSIS

Pub. No.	Author/Publication	BRW Status	Operational Issues: Traffic Flow Characteristics: Speed	Flow	Density/ Occpncy	Freeway Tffc. Mgt.	Capacity	Headway	AADT	Accident Characteristics: Rates	Types	Severity	E. of Frwy T. Mgt.
1	Fenton, R. and Mayhan, R. "Automated Highway Studies at the Ohio St. U.--An Overview" IEEE Transactions on Vehicular Technology, Vol. 40, No. 1 February, 1991	have BRW 9/14/93					U-2 U-3						
2	Elias, J., et al "Practicality of Automated Highway Systems, Vol I: Summary Rpt" Report No. FHWA-RD-79-39 November, 1977	have BRW 9/22/93					U-4 U-2A F-4 F-2A						
3	Bender, J. "An Overview of Systems Studies of Automated Hwy Systems" IEEE Transactions on Vehicular Technology, Vol. 40, No. 1 February, 1991	have BRW 9/14/93	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4		U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4					
4	Tsao, H.S.J., Hall, R.W., Shladover, S.E., Plocher, T.A., Levitan, L. "Human Factors Dsgn of Atmtd Hwy Sys (AHS), 1st Gen.Scnrios" Working Paper on DTFH61-92-C-00100, FHWA 1993	have BRW 9/14/93											
5	Federal Highway Administration "Precursor Systems Analyses of Automated Highway Systems" FHWA RFP No. DTFH-61-93-R-00047 November, 1992	have BRW Battelle 3/1/93											
6	Bishop, J. R. "Status Report on the AHS Program" Presented at Autonomous Unmanned Veh. Soc. Ann. Mtg., June 28-30, 1993 in Washington, D.C.	have BRW 9/14/93											
7	"Supplemtry Descrptn of AHS (DRAFT)" FHWA distributed draft for AHS project September, 1993	have BRW 9/14/93	2	2	2	2	2	2	2				
8	Stevens, W. "The Automated Hwy System (AHS) Concepts Analysis (DRAFT)" MITRE Tech. Rep. MTR 93W0000123, McLean, VA August, 1993	have BRW Aug-93				2	2						
9	"IVHS Strategic Plan -- Report to Congress" U.S. Dept. of Transportation December, 1992	have BRW 8/1/93											
10	Shladover, S.E., et al. "Automatic Veh. Control Developments in the PATH Program" IEEE Transactions on Vehicular Technlgy, Vol. 40, No. 1, N.Y. February, 1991	have BRW 9/14/93						U-2					

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Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS — Operational Issues — Traffic Flow Characteristics: Speed	Flow	Density/ Occpncy	Freeway Tffc. Mgt.	Capacity	Headway	AADT	Accident Characteristics: Rates	Types	Severity	E. of Frwy T. Mgt.
11	Fenton, R., Mayhan, R., et al. "Fundamental Studies in Automatic Vehicle Control" Rep. No. FHWA/RD-80/198, The Ohio St. U. August, 1981	have BRW 9/22/93 Mfiche Ex.Sum		U-1 R-1	U-1 R-1	U-1 R-1	U-1 R-1						
12	Bender, J.G., Bonderson, L.S., et al. "System Studies of Automated Highway Systems - Final Report" Rep. No. FHWA/RD-82-003, GMotors Transp. Sys. Ctr., Warren,MI August, 1981	have BRW 9/22/93 Mfiche Ex.Sum	U-1 R-1 U-4 R-4	U-1 R-1 U-4 R-4	U-1 R-1 U-4 R-4	U-1 R-1 U-4 R-4 U-3	U-1 R-1 U-4 R-4	U-1 R-1 U-4 R-4					
13	Chang, K.S., Hedrick, Zhang, Varaiya, Tomizuka, and Shladover "Automated Hwy Sys Experiments in the PATH Program" IVHS Journal, Vol. 1(1), pp. 63-87 1993	have BRW 9/14/93	U-2C					U-2C					
14	Chang, K.S., et al. "Experimentation with a Veh. Platoon Control System" Veh. Navgtn & Info. Sys Conf., Paper No. 912868 Dearborn, MI 1991	have BRW 9/22/93					U-2 R-2						
15	Smith, Dirk E., and Starkey, John M. "Overview of Veh. Modls, Dynmics, & Cntrl Appl'd to Automtd Veh." Advanced Automotive Technologies, Winter Ann. Mtg. ASME December, 1991	have BRW 10/4/93	U-1 R-2 R-4 U-2B,U-2C										
16	Bresnock, A., Miller, M., Lechner, E. "Hwy Automation: System Modeling for Impacts Analysis" Veh. Navgtn & Info Sys. Conf. Procdgs, Dearborn, MI October 20-23, 1991	have BRW 9/22/93	U-2A	U-2A			U-2A		U-2A				
17	Niehaus, Axel and Stengel, Robert F. "Probability-Based Decision Making for Atm'd Hwy Driving" Veh. Navgtn & Info Sys. Conf. Procdgs, Dearborn, MI Pt. 2, SAE October 20-23, 1991, (#912869)	have BRW 9/22/93	U-2A					U-2A					
18	Lafortune, S., Sengupta, R., Kaufman, D., & Smith, R. "A Dynamical Sys. Model for Traffic Assignment in Networks" Veh. Navgtn & Info Sys. Conf. Procdgs, Dearborn, MI Pt. 2, SAE October 20-23, 1991, (#912869)	have BRW 9/22/93											
19	Johnston, R.A., DeLuchi, M.A., Sperling, D. and Craig, P.P. "Automating Urban Freeways: Policy Research Agenda" J. of Transp. Eng. Vol. 116 No. 4, ASCE July 1, 1990	have BRW 10/4/93	U-4		U-4		U-4	U-4	U-4				
20	Anwar, Mohammed and Jovanis, Paul "Assessing the Safety Benefits of Automated Freeways" for PATH, U. Ca. Davis, UCB-ITS-PRR-93-29 December, 1993	Have BRW 5/18/94								U-3 U-2B	U-3 U-2B	U-3 U-2B	

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			ACTIVITY AREA A: URBAN AND RURAL ANALYSIS										
			Operational Issues										
			Traffic Flow Characteristics							Accident Characteristics			
Pub. No.	Author/Publication	BRW Status	Speed	Flow	Density/ Occpncy	Freeway Tffc. Mgt.	Capacity	Headway	AADT	Rates	Types	Severity	E. of Frwy T. Mgt.
21	Deakin, Elizabeth A. "Opportunities and Constraints for Ad. Hwy. Technlgies: A Speculitiv PATH, U. Ca. Berkeley, UCB-ITS-PRR-89-7 October, 1989	Have BRW 5/18/94											
22	Hall, Randolph W. and Kamoun, Mahdi "Evaluation of Highway Bottlenecks" PATH, U. Ca. Berkeley, UCB-ITS-PRR-91-9 July, 1991	Have BRW 5/18/94			U-2		U-2						
23	Varaiya, Pravin and Shladover, Steven E. "Sketch of an IVHS Systems Architecture" PATH, U. Ca. Berkeley, UCB-ITS-PRR-91-3 February, 1991	Have BRW 5/18/94											
24	McMahon, Donn H. and Hedrick, Karl J. "Longitudinal Model Development for Automated Roadway Vehicles" PATH, U. Ca. Berkeley, UCB-ITS-PRR-89-5 October, 1989	Have BRW 5/18/94											
25	Eskafi, Farokh; Khorramabadi, Delnaz, and Varaiya, Pravin "SmartPath: An Automated Highway System Simulator" PATH, U. Ca. Berkeley, Tech. Memo. 92-3 23-Oct-92	Have BRW 5/18/94	U-2A TWO LANES	U-2A TWO LANES	U-2A TWO LANES		U-2A TWO LANES						
26	Varaiya, Pravin "Smart Cars on Smart Roads: Problems of Control" PATH, U. Ca. Berkeley, Tech. Memo. 91-5 December, 1991	Have BRW 5/18/94											
27	Shladover, Steven E. "Potential Contributions of IVHS to Reducing Transportation's Green PATH, U. Ca. Berkeley, Tech. Memo. 91-4 August, 1991	Have BRW 5/18/94					U-2						
28	Rockwell International Science Center "Potential Payoffs from IVHS: A Framework for Analysis" PATH, U. Ca. Berkeley, UCB-ITS-PRR-92-7 August, 1992	Have BRW 5/18/94	U-2	U-2	U-2	U-2	U-2	U-2		U-2	U-2	U-2	U-2
29	Hall, Randolph W. "Time Benefits of New Transportation Technologies: The Case of Hig PATH, U. Ca. Berkeley, UCB-ITS-PWP-91-4 June, 1991	Have BRW 5/18/94	U-2	U-2	U-2	U-2	U-2						
30	Scapinakis, Dimitris A. and Garrison, William L. "Communications and Positioning Systems in the Motor Carrier Indus PATH, U. Ca. Berkeley, UCB-ITS-PRR-91-10 1991	Have BRW 5/18/94											

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Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA A: URBAN AND RURAL ANALYSIS										
			Operational Issues										
			Traffic Flow Characteristics							Accident Characteristics			
			Speed	Flow	Density/ Occpncy	Freeway Tffc. Mgt.	Capacity	Headway	AADT	Rates	Types	Severity	E. of Frwy T. Mgt.
31	Ritchie, Stephen G. and Cheu, Ruey L. "Neural Network Models for Automated Detection on Non-Recurring (PATH, U. Ca. Berkeley, UCB-ITS-PRR-93-5 June, 1993	Have BRW 5/18/94											
32	Polydoros, Andreas "Vehicle to Roadside Communications Study" PATH, U. Ca. Berkeley, UCB-ITS-PRR-93-4 June, 1993	Have BRW 5/18/94											
33	Hsu, Ivy Pen-Shan and Walrand, Jean "Communication Requirements and Network Design for IVHS" PATH, U. Ca. Berkeley, UCB-ITS-PWP-93-18 November, 1993	Have BRW 5/18/94											

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Pub. No.	Author/Publication	BRW Status	Trip Characteristics: Length	Trip Characteristics: Purpose	Trip Characteristics: Time of Trip	ACTIVITY AREA E: MALFUNCTION MANAGEMENT AND ANALYSIS: Potential Malfunction Identification	ACTIVITY AREA E: Malfunction Management Strategies	ACTIVITY AREA E: Consequences of Collisions	ACTIVITY AREA E: Measures of Effectiveness	ACTIVITY AREA H: AHS RDWY DVLPMT Candidate Site Selection: Generalized Urban	Generalized Rural	Real-World Urban	Real-World Rural
1	Fenton, R. and Mayhan, R. "Automated Highway Studies at the Ohio St. U.--An Overview" IEEE Transactions on Vehicular Technology, Vol. 40, No. 1 February, 1991	have BRW 9/14/93											
2	Elias, J., et al "Practicality of Automated Highway Systems, Vol I: Summary Rpt" Report No. FHWA-RD-79-39 November, 1977	have BRW 9/22/93			U-4 U-2A F-4 F-2A					U-4 U-2A	F-4 F-2A		
3	Bender, J. "An Overview of Systems Studies of Automated Hwy Systems" IEEE Transactions on Vehicular Technology, Vol. 40, No. 1 February, 1991	have BRW 9/14/93								U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4
4	Tsao, H.S.J., Hall, R.W., Shladover, S.E., Plocher, T.A., Levitan, L. "Human Factors Dsgn of Atmtd Hwy Sys (AHS), 1st Gen.Scnrios" Working Paper on DTFH61-92-C-00100, FHWA 1993	have BRW 9/14/93				R-4 U-4	R-4 U-4						
5	Federal Highway Administration "Precursor Systems Analyses of Automated Highway Systems" FHWA RFP No. DTFH-61-93-R-00047 November, 1992	have BRW Battelle 3/1/93											
6	Bishop, J. R. "Status Report on the AHS Program" Presented at Autonomous Unmanned Veh. Soc. Ann. Mtg., June 28-30, 1993 in Washington, D.C.	have BRW 9/14/93											
7	"Supplemtry Descrptn of AHS (DRAFT)" FHWA distributed draft for AHS project September, 1993	have BRW 9/14/93								2			
8	Stevens, W. "The Automated Hwy System (AHS) Concepts Analysis (DRAFT)" MITRE Tech. Rep. MTR 93W0000123, McLean, VA August, 1993	have BRW Aug-93											
9	"IVHS Strategic Plan -- Report to Congress" U.S. Dept. of Transportation December, 1992	have BRW 8/1/93											
10	Shladover, S.E., et al. "Automatic Veh. Control Developments in the PATH Program" IEEE Transactions on Vehicular Technlgy, Vol. 40, No. 1, N.Y. February, 1991	have BRW 9/14/93											

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13	Chang, K.S., Hedrick, Zhang, Varaiya, Tomizuka, and Shladover "Automated Hwy Sys Experiments in the PATH Program" IVHS Journal, Vol. 1(1), pp. 63-87 1993	have BRW 9/14/93								U-2C	R-2C		
14	Chang, K.S., et al. "Experimentation with a Veh. Platoon Control System" Veh. Navgtn & Info. Sys Conf., Paper No. 912868 Dearborn, MI 1991	have BRW 9/22/93				U-2 R-2	U-2 R-2			U-2			
15	Smith, Dirk E., and Starkey, John M. "Overview of Veh. Modls, Dynmics, & Cntrl Appl'd to Automtd Veh." Advanced Automotive Technologies, Winter Ann. Mtg. ASME December, 1991	have BRW 10/4/93				U-1 R-2 R-4 U-2B,U-2C	U-1 R-2 R-4 U-2B,U-2C						
16	Bresnock, A., Miller, M., Lechner, E. "Hwy Automation: System Modeling for Impacts Analysis" Veh. Navgtn & Info Sys. Conf. Procdgs, Dearborn, MI October 20-23, 1991	have BRW 9/22/93	U-2A							U-2A		U-2A	
17	Niehaus, Axel and Stengel, Robert F. "Probability-Based Decision Making for Atm'd Hwy Driving" Veh. Navgtn & Info Sys. Conf. Procdgs, Dearborn, MI Pt. 2, SAE October 20-23, 1991, (#912869)	have BRW 9/22/93								U-2A			
18	Lafortune, S., Sengupta, R., Kaufman, D., & Smith, R. "A Dynamical Sys. Model for Traffic Assignment in Networks" Veh. Navgtn & Info Sys. Conf. Procdgs, Dearborn, MI Pt. 2, SAE October 20-23, 1991, (#912869)	have BRW 9/22/93	U-2B R-2B		U-2B R-2B								
19	Johnston, R.A., DeLuchi, M.A., Sperling, D. and Craig, P.P. "Automating Urban Freeways: Policy Research Agenda" J. of Transp. Eng. Vol. 116 No. 4, ASCE July 1, 1990	have BRW 10/4/93			U-4								
20	Anwar, Mohammed and Jovanis, Paul "Assessing the Safety Benefits of Automated Freeways" for PATH, U. Ca. Davis, UCB-ITS-PRR-93-29 December, 1993	Have BRW 5/18/94						U-3 U-2B					

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21	Deakin, Elizabeth A. "Opportunities and Constraints for Ad. Hwy. Technigies: A Speculitiv PATH, U. Ca. Berkeley, UCB-ITS-PRR-89-7 October, 1989	Have BRW 5/18/94											
22	Hall, Randolph W. and Kamoun, Mahdi "Evaluation of Highway Bottlenecks" PATH, U. Ca. Berkeley, UCB-ITS-PRR-91-9 July, 1991	Have BRW 5/18/94	U-2	U-2	U-2								
23	Varaiya, Pravin and Shladover, Steven E. "Sketch of an IVHS Systems Architecture" PATH, U. Ca. Berkeley, UCB-ITS-PRR-91-3 February, 1991	Have BRW 5/18/94											
24	McMahon, Donn H. and Hedrick, Karl J. "Longitudinal Model Development for Automated Roadway Vehicles" PATH, U. Ca. Berkeley, UCB-ITS-PRR-89-5 October, 1989	Have BRW 5/18/94											
25	Eskafi, Farokh; Khorramabadi, Delnaz, and Varaiya, Pravin "SmartPath: An Automated Highway System Simulator" PATH, U. Ca. Berkeley, Tech. Memo. 92-3 23-Oct-92	Have BRW 5/18/94								U-2A TWO LANES	U-2A TWO LANES		
26	Varaiya, Pravin "Smart Cars on Smart Roads: Problems of Control" PATH, U. Ca. Berkeley, Tech. Memo. 91-5 December, 1991	Have BRW 5/18/94	U-2	U-2	U-2								
27	Shladover, Steven E. "Potential Contributions of IVHS to Reducing Transportation's Greeni PATH, U. Ca. Berkeley, Tech. Memo. 91-4 August, 1991	Have BRW 5/18/94	U-2		U-2					U-2			
28	Rockwell International Science Center "Potential Payoffs from IVHS: A Framework for Analysis" PATH, U. Ca. Berkeley, UCB-ITS-PRR-92-7 August, 1992	Have BRW 5/18/94	U-2	U-2	U-2					2			
29	Hall, Randolph W. "Time Benefits of New Transportation Technologies: The Case of Hig PATH, U. Ca. Berkeley, UCB-ITS-PWP-91-4 June, 1991	Have BRW 5/18/94	U-2	U-2	U-2					2			
30	Scapinakis, Dimitris A. and Garrison, William L. "Communications and Positioning Systems in the Motor Carrier Indus PATH, U. Ca. Berkeley, UCB-ITS-PRR-91-10 1991	Have BRW 5/18/94											

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31	Ritchie, Stephen G. and Cheu, Ruey L. "Neural Network Models for Automated Detection on Non-Recurring (PATH, U. Ca. Berkeley, UCB-ITS-PRR-93-5 June, 1993	Have BRW 5/18/94											
32	Polydoros, Andreas "Vehicle to Roadside Communications Study" PATH, U. Ca. Berkeley, UCB-ITS-PRR-93-4 June, 1993	Have BRW 5/16/94											
33	Hsu, Ivy Pen-Shan and Walrand, Jean "Communication Requirements and Network Design for IVHS" PATH, U. Ca. Berkeley, UCB-ITS-PWP-93-18 November, 1993	Have BRW 5/18/94											

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Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA I: IMPACT OF AHS ON SURROUNDING NON-AHS ROADWAYS: Risk on Ex. Non-AHS	Mitigation of Risks	Redesign of Ex. Rdwys	Maximize Benefits of AHS Plcmt	Modeling: Traffic Forecasts	Modeling: Noise Analysis	Modeling: Air Quality Analysis	ACTIVITY AREA J: ENTRY/EXIT IMPLEMENTATION: Candidate Exit/Entry Strategies	Measures of Effectiveness	Exit/Entry Evaluation Techniques	ACTIVITY AREA K: AHS RDWY OP. ANALYSIS: Resource Reqmts	Capital Costs	O & M Costs
1	Fenton, R. and Mayhan, R. "Automated Highway Studies at the Ohio St. U.--An Overview" IEEE Transactions on Vehicular Technology, Vol. 40, No. 1 February, 1991	have BRW 9/14/93													
2	Elias, J., et al "Practicality of Automated Highway Systems, Vol I: Summary Rpt" Report No. FHWA-RD-79-39 November, 1977	have BRW 9/22/93	U-2A U-4 F-2A F-4	U-2A U-4 F-2A F-4	U-2A U-4 F-2A F-4	U-2A U-4 F-2A F-4							U-2A U-4 F-2A F-4	U-2A U-4 F-2A F-4	U-2A U-4 F-2A F-4 u3
3	Bender, J. "An Overview of Systems Studies of Automated Hwy Systems" IEEE Transactions on Vehicular Technology, Vol. 40, No. 1 February, 1991	have BRW 9/14/93	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4	U-1 U-4 R-1 R-4
4	Tsao, H.S.J., Hall, R.W., Shladover, S.E., Plocher, T.A., Levitan, L. "Human Factors Dsgn of Atmtd Hwy Sys (AHS), 1st Gen.Scnrios" Working Paper on DTFH61-92-C-00100, FHWA 1993	have BRW 9/14/93								R-4 U-4	R-4 U-4	R-4 U-4			
5	Federal Highway Administration "Precursor Systems Analyses of Automated Highway Systems" FHWA RFP No. DTFH-61-93-R-00047 November, 1992	have BRW Battelle 3/1/93													
6	Bishop, J. R. "Status Report on the AHS Program" Presented at Autonomous Unmanned Veh. Soc. Ann. Mtg., June 28-30, 1993 in Washington, D.C.	have BRW 9/14/93								2	2	2			
7	"Supplemtry Descrptn of AHS (DRAFT)" FHWA distributed draft for AHS project September, 1993	have BRW 9/14/93	2	2	2	2	2	2	2	2	2	2			
8	Stevens, W. "The Automated Hwy System (AHS) Concepts Analysis (DRAFT)" MITRE Tech. Rep. MTR 93W0000123, McLean, VA August, 1993	have BRW Aug-93	2	2	2	2	2	2	2	2		2		2	
9	"IVHS Strategic Plan -- Report to Congress" U.S. Dept. of Transportation December, 1992	have BRW 8/1/93													
10	Shladover, S.E., et al. "Automatic Veh. Control Developments in the PATH Program" IEEE Transactions on Vehicular Technlgy, Vol. 40, No. 1, N.Y. February, 1991	have BRW 9/14/93													

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							Modeling								
			Risk on Ex. Non-AHS	Mitigation of Risks	Redesign of Ex. Rdwys	Maximize Benefits of AHS Plcmt	Traffic Forecasts	Noise Analysis	Air Quality Analysis	Candidate Exit/Entry Strategies	Measures of Effectiveness	Exit/Entry Evaluation Techniques	Resource Reqmts	Capital Costs	O & M Costs
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13	Chang, K.S., Hedrick, Zhang, Varaiya, Tomizuka, and Shladover "Automated Hwy Sys Experiments in the PATH Program" IVHS Journal, Vol. 1(1), pp. 63-87 1993	have BRW 9/14/93													
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16	Bresnock, A., Miller, M., Lechner, E. "Hwy Automation: System Modeling for Impacts Analysis" Veh. Navgtn & Info Sys. Conf. Procdgs, Dearborn, MI October 20-23, 1991	have BRW 9/22/93							U-2A					U-2A	
17	Niehaus, Axel and Stengel, Robert F. "Probability-Based Decision Making for Atm'd Hwy Driving" Veh. Navgtn & Info Sys. Conf. Procdgs, Dearborn, MI Pt. 2, SAE October 20-23, 1991, (#912869)	have BRW 9/22/93													
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19	Johnston, R.A., DeLuchi, M.A., Sperling, D. and Craig, P.P. "Automating Urban Freeways: Policy Research Agenda" J. of Transp. Eng. Vol. 116 No. 4, ASCE July 1, 1990	have BRW 10/4/93	U-4	U-4	U-4	U-4		U-4	U-4				U-4	U-4	U-4
20	Anwar, Mohammed and Jovanis, Paul "Assessing the Safety Benefits of Automated Freeways" for PATH, U. Ca. Davis, UCB-ITS-PRR-93-29 December, 1993	Have BRW 5/18/94								U-3 U-2B	U-3 U-2B				

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30	Scapinakis, Dimitris A. and Garrison, William L. "Communications and Positioning Systems in the Motor Carrier Indu PATH, U. Ca. Berkeley, UCB-ITS-PRR-91-10 1991	Have BRW 5/18/94													

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1	Fenton, R. and Mayhan, R. "Automated Highway Studies at the Ohio St. U.--An Overview" IEEE Transactions on Vehiclular Technology, Vol. 40, No. 1 February, 1991	have BRW 9/14/93													
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4	Tsao, H.S.J., Hall, R.W., Shladover, S.E., Plocher, T.A., Levitan, L. "Human Factors Dsgn of Atmtd Hwy Sys (AHS), 1st Gen.Scnrios" Working Paper on DTFH61-92-C-00100, FHWA 1993	have BRW 9/14/93										R-4 U-4	R-4 U-4	R-4 U-4	R-4 U-4
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8	Stevens, W. "The Automated Hwy System (AHS) Concepts Analysis (DRAFT)" MITRE Tech. Rep. MTR 93W0000123, McLean, VA August, 1993	have BRW Aug-93						2		2	2				
9	"IVHS Strategic Plan -- Report to Congress" U.S. Dept. of Transportation December, 1992	have BRW 8/1/93													
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					Institutional Aspects			Societal Aspects							
			Safety and Risks	Potential Mitigation of Risks	Relevant Orgnztns	Legal/Regltry Framework	Policy Making	Public Acceptability	Stkhldr Issues	Social & Ec Effects	Public Perception	Manual to Automatic Mode	Operation in Automatic Mode	Emergency Issues	Automatic to Manual Mode
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13	Chang, K.S., Hedrick, Zhang, Varaiya, Tomizuka, and Shladover "Automated Hwy Sys Experiments in the PATH Program" IVHS Journal, Vol. 1(1), pp. 63-87 1993	have BRW 9/14/93													
14	Chang, K.S., et al. "Experimentation with a Veh. Platoon Control System" Veh. Navgtn & Info. Sys Conf., Paper No. 912868 Dearborn, MI 1991	have BRW 9/22/93													
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U,F,R = Urban, Fringe, or Rural Setting; Numbers refer to applicable RSC(s)

Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA N: AHS SAFETY ISSUES		ACTIVITY AREA O: INSTITUTIONAL AND SOCIETAL ASPECTS							HUMAN FACTORS			
					Institutional Aspects			Societal Aspects							
			Safety and Risks	Potential Mitigation of Risks	Relevant Orgnztns	Legal/Regltry Framework	Policy Making	Public Acceptability	Stkhldr Issues	Social & Ec Effects	Public Perception	Manual to Automatic Mode	Operation in Automatic Mode	Emergency Issues	Automatic to Manual Mode
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29	Hall, Randolph W. "Time Benefits of New Transportation Technologies: The Case of Hig PATH, U. Ca. Berkeley, UCB-ITS-PWP-91-4 June, 1991	Have BRW 5/18/94													
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Pub. No.	Author/Publication	BRW Status	ACTIVITY AREA N: AHS SAFETY ISSUES		ACTIVITY AREA O: INSTITUTIONAL AND SOCIETAL ASPECTS							HUMAN FACTORS			
					Institutional Aspects			Societal Aspects							
			Safety and Risks	Potential Mitigation of Risks	Relevant Orgnztns	Legal/Regltry Framework	Policy Making	Public Acceptability	Stkhldr Issues	Social & Ec Effects	Public Perception	Manual to Automatic Mode	Operation in Automatic Mode	Emergency Issues	Automatic to Manual Mode
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32	Polydoros, Andreas "Vehicle to Roadside Communications Study" PATH, U. Ca. Berkeley, UCB-ITS-PRR-93-4 June, 1993	Have BRW 5/18/94													
33	Hsu, Ivy Pen-Shan and Walrand, Jean "Communication Requirements and Network Design for IVHS" PATH, U. Ca. Berkeley, UCB-ITS-PWP-93-18 November, 1993	Have BRW 5/18/94													

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APPENDIX B

FIRST WORKSHOP ATTENDEES

APPENDIX B

FIRST WORKSHOP ATTENDEES

Automated Highway Systems
Precursor Study Workshop

Eiji Amito
Badge Number: 13
Honda Motor Co., Inc.
955 L'Enfant Plaza, #5300, SW
Washington, DC 20024
Phone: 202-554-1650
FAX: 202-488-35402

Richard Barber
Badge Number: 6
Rockwell
AESD
3370 Miraloma
Mailstop FB25
Anaheim, CA 92803-3150
Phone: 714-762-3450
FAX: 714-762-0130

Jeffrey L. Benson
Badge Number: 44
BRW, Inc.
700 3rd Street South
Minneapolis, MN 55415
Phone: 612-373-6389
FAX: 612-370-1378

Dick Bishop
Badge Number: 46
DOT/FHWA
6300 Georgetown Pike (HSR 10)
McLean, VA 22101
Phone: 703-285-2680
FAX:

Douglas H. Differt
Badge Number: 45
BRW, Inc.
700 3rd Street South
Minneapolis, MN 55415
Phone: 612-373-6339
FAX: 370-1378

Richard P. Braun
Director
Center for Transportation Studies
Badge Number: 27
University of Minnesota
110 Civil and Mineral Eng. Bldg.
500 Pillsbury Drive, SE
Minneapolis, MN 55455-0220
Phone: 612-626-1077
FAX: 612-625-6381

David W. Bruggeman
Badge Number: 14
BRW, Inc.
2700 North Central Avenue
Suite 1000
Phoenix, AZ 85004
Phone: 602-234-1591, x224
FAX: 602-230-9189

Glen C. Carison
Mgr. - Traffic Mgmt. Center
Badge Number: 62
Minnesota DOT
1101 - 4th Avenue South
Minneapolis, MN 55404-1022
Phone:
FAX:

Salvatore Sam Castronovo
Badge Number: 54
Envirodyne Eng. Inc.
10610 Bobsyl Lane
Grand Ledge, MI 48837
Phone: 517-323-8200
FAX: 517-323-8210

Jeff Davis
Badge Number: 19
TRW
495 Java Dr.
Sunnyvale, CA 95129
Phone: 408-743-6367
FAX: 408-743-6425

Thomas B. Deen
Executive Director
Badge Number: 72
Transportation Research Board
2101 Constitution Avenue, NW
Washington, DC 20418
Phone:
FAX:

Vincent R. DeMarco
Badge Number: .11
US DOT/FTA
400 7th Street, SW
Washington, DC 22213
Phone: 202-366-0224
FAX: 202-366-3765

William F. Edward's
Engineer
Bureau of Research & Development
Badge Number: 65
Ohio Department of Transportation
25 South Front Street
Columbus, OH 53215
Phone: 614-752-5272
FAX:

Joe Elias
Badge Number: 32
Calspan Corp.
Software Technology
P0 Box 400
Buffalo, NY 14225
Phone: 716-631-6813
FAX: 716-631-6722

Robert D. Ervin
Research Scientist
Badge Number: 34
University of Michigan
Transportation Research Institute
2901 Baxter Road, Room 211
Ann Arbor, MI 48109
Phone: 313-936-1066
FAX:

Paul Fancher
Badge Number: 35
University of Michigan
2901 Baxter Road
Ann Arbor, MI 48109
Phone: 313-936-1059
FAX: 313-936-1068

Dennis Foderberg
Badge Number: 28
University of Minnesota
110 CMA Building
Minneapolis, MN 55455
Phone: 612-626-8285
FAX: 612-625-6381

H. Jonathon Frank
Vice President, Sales
Badge Number: 29
Barrier Systems Inc.
1100 East William Street, Suite 206
Carson City, NV 89701-3104
Phone:
FAX:

Thomas M. Franks
Badge Number: 30
Raytheon Company
111 Park Drive, #52
Boston, MA 02215
Phone: 617-262-7996
FAX: 508-858-4757

Franz Ginunler
Badge Number: 51
Federal Transit Administration
400 - 7th Street, SW, Room 6432
Washington, DC 20590
Phone: 202-366-7896
FAX:

Alan T. Gonseth
President
Badge Number: 42
Gonseth Associates Inc.
660 Sultan Lane
Schodack Landing, NY 12156
Phone: 516-732A594
FAX:

John Harding
Badge Number: 5
MITRE Corporation
600 Maryland Avenue, SW
Suite 755
Washington, DC 20024
Phone: 202A88-5703
FAX: 202-

Bob Henke
Badge Number: 59
Minnesota Department of Transportation
Transportation Building
395 John Irelartd Boulevard
St. Paul, MN 55155

Milton Heywood
Badge Number: 57
Federal Highway Administration
400 - 7th Street, SW, HTV-11
Washington, DC 20590-
Phone: 202-366-2182
FAX:

Antoine G. Hobeika
Badge Number: 71
Director
Virginia Polytechnic Institute
Center for Transportation Research
106 Faculty Street
Blacksburg, VA 24061
Phone: 703-231-7740
FAX: 703-231-5214

Ardell Hoveskeland
Badge Number: 43
Advance
1133 15th Street, NW
Washington, DC
Phone: 202-775-3365
FAX: 202-775-3389

Robert D. James
Badge Number: 2
Virginia Tech
Phone: 301-208-8000
FAX: 301-208-0500

Dennis L. Kershner
Transportation Team Leader
Badge Number: 24
Johns HopkinsUniversity
Applied Physics Laboratory
Johns Hopkins Road
Laurel, MD 20723
Phone:
FAX:

Snehamay Khasnabis
Badge Number: 50
Wayne State University
5050 Anthony Wayne Drive
Detroit, Ml 48202
Phone: 313-577-3915
FAX: 313-577-3881

Ty Lasky
Badge Number: 15
University of California-Davis
Department of Mechanical Engineering
Davis, CA 95616
Phone: 916-752-5866
FAX: 916-752-6714

Jeffrey A. Lindley
Badge Number: 39
Federal Highway Administration
211 Main Street, Room 1100
San Francisco, CA 94105
Phone: 415-744-2659
FAX: 415-744-2620

Adam Lubliner
Badge Number: 70
Phone: 212465-5412
FAX:

Don Lucas
Chief Highway Engineer
Badge Number: 9
Indiana Department of Transportation
State Office Building
100 North Senate Avenue
Indianapolis, IN 46204-2249
Phone: 317-232-5529
FAX:

Robert E. Maid
Badge Number: 25
Michigan DOT
P0 Box 30050
Lansing, MI 48909
Phone: 517-373-2247
FAX:

Mike Martin
Badge Number: 60
BDM
Fairfax 2B-232
1501 BDM Way
McLean, VA 22102
Phone: 708-84g-596
FAX:

John M. Mason, Jr.
Professor and Director
Badge Number: 37
Pennsylvania State University
Pennsylvania Transportation Institute
201 Research Office Building
University Park, PA 168024710
Phone:
FAX:

Kimberley Mastako
Badge Number: 58
CalPoly - SLO
Building 4, Room 106
San Luis Obispo, CA 93407
Phone: 805-756-6109
FAX: 805-756-1202

Bill McCall
Associate Director
Badge Number: 66
Iowa Transportation Center
Iowa State University
194 Town Engineering Building
Ames, IA 50011
Phone: 515-294-8103
FAX: 515-294-0467

Cheryl McConnell
Badge Number: 16
BRW, Inc.
620 C Street
San Diego, CA 92101
Phone: 619-557-0850
FAX: 619-557-8307

Thomas J. McGean
Consulting Engineer
Badge Number: 47
3711 Spicewood Drive
Annandale, VA 22003-2250
Phone: 703-280-2299
FAX:

Gene McHale
Badge Number: 49
MITRE Corporation
600 Maryland Avenue, SW
Suite 755
Washington, DC 20024
Phone: 202-863-2984
FAX: 202-863-2988

Mark Miller
Badge Number: 40
University of California
PATH
Richmond Field Station
1301 South 46th Street
Building 452
Richmond, CA94804
Phone: 510-231-9465
FAX: 510-231-5600

Pitu B. Mirchandani
Professor and Department Head
Badge Number: 56
University of Arizona
Sys. and Indus. Engineering Dept.
Tucson, AZ 85721
Phone: 602-621-6551
FAX:

David J. Mitchell
V.P. Marketing, Trans. Systems
Badge Number: 17
Battelle
Room 11-7-129B
505 King Street
Columbus, OH 43201
Phone: 614-424-4929
FAX: 614-424-5069

Michael W. Moulton
Badge Number: 21
Sandia National Labs/Alliance for Transportation Research
1001 University Boulevard, SE
Albuquerque, NM 87106A342
Phone: 505-246-6410
FAX: 505-246-6001

Shimon Nof
Badge Number: 73
Phone: 617-494-5427
FAX:

Ken Oprela
Badge Number: 64
Transportation Research Board
2101 Constitution Avenue, NW
Washington, DC 20418
Phone: 202-334-2934
FAX:

Jeff Ottesen
BRW, Inc.
Thresher Square
700 3rd Street South
Minneapolis, MN 55415
Phone: 612-370-0700

Robert D. Owens, PE.
Senior Traffic Engineering Specialist
Badge Number: 63
3M Facilities Engineering & Real Estate
3M Center Building. 42-8E-4
900 Bush Avenue
St. Paul, MN 55144-1000

Jerry Pittenger
Badge Number: 10
Battelle
505 King Street, Roorn 117-073
Columbus, OH 43201-2693
Phone: 614-424-5189
FAX:

Jean Yves Point-Du-Jour
Badge Number: 67
Maryland State Highway
7491 Connelly Drive
Hanover, MD
Phone: 410-787-5866
FAX:

Howard Preston
BRW, Inc.
Thresher Square
700 3rd Street South
Minneapolis, MN 55415
Phone: 612-370-0700

Ivy Renga
Manager, IVHS Programs
Badge Number: 22
Chrysler Corporation
CIMS: 46-00-00
30900 Stephenson Highway
Madison Heights, MI 48071
Phone:
FAX:

James R. Robinson
Badge Number: 26
Federal Highway Administration
31 Hopkins Plaza
Baltimore, MD 21201
Phone: 202-366-2221
FAX:

Mike Robinson
Director of Traffic Engineering
Badge Number: 33
Minnesota Department of Transportation
Transportation Building
395 John Ireland Boulevard
St. Paul, MN 55155
Phone: 612-
FAX: 612-

Stephen C. Rochrig
Badge Number:
Sandia National Laboratories
&X 5800, Org. 9604
Albuquerque, NM 87185-5800
Phone: 505-844-1180
FAX: 505-844-2193

Phyllis Rodlinski
Badge Number: 8
Transportation Research Center
10820 State Route 347
East Liberty, OH 43310-0367
Phone: 513-666-2011
FAX: 513-666-5066

Randy Schuize
Badge Number: 5
DMJM
300 West Clarendon Avenue, Suite 300
Phoenix, AZ 85013A)217
Phone: 602-264-0217
FAX: 602-285-1984

Habib Shanskhoo
Badge Number: 58
Parsons-Brink, NY
One Penn Plaza
250 West 34th Street
New York, NY 10119
Phone: 212465-5136
FAX:

Egan R. Smith
Badge Number: 18
Dunn Engineering
66 Main Street
West Hampton Beach, NY 11978
Phone: 516-288-2480
FAX: 516-288-2544

Ronald C. Sonntag
Dist. Chief Freeway Engineer
Badge Number: 68
Wisconsin DOT
141 NW Barstow Street
P0 Box 647
Waukesha, WI 53188-3789
Phone: 414-548-6766
FAX:

Bill Starens
Badge Number: 52
MITRE Corporation
600 Maryland Avenue, SW
Washington, DC 20024
Phone: 202-863-29
FAX: 202-863-2988

Denis J. Symes
Badge Number: 7
USDOT/FTA
400 7th Street, RM 6102
Washington, DC 22213
Phone: 202-366-0232
FAX:202-366-3765

Peggy Tadej
Badge Number: 41
Lockheed
1200 K Street, NW, Suite 1200
Washlngton, DC 20005
Phone: 202-659-0086
FAX: 202-293-4300

James Vandel
Transp. Programming Engineer
Badge Number: 3
Wyoming Department of Transportation
PO Box 1708
Cheyenne, WY 82002-9019
Phone: 307-7774490
FAX: 307-7774759

Cary D. Vick
Badge Number: 32
SAIC
1710 Goodridge Drive
MailStop 1-6-2
McLean, VA 22182
Phone: 703-7344028
FAX: 703-821-1037

C. Michael Walton
Chairman, Dept of Civil Eng.
Badge Number: 61
University of Texas at Austin
Ernest Cockrell Jr. Hall 4.2
Austin, TX 78712
Phone: 512471-1414
FAX: 5124714995

J.D. Ward
Badge Number: 55
Rockwell International
2049 Hidden Springs Drive
El Cajon, CA 92019
Phone: 619442-3432
FAX:

Dick Weaver
Deputy Director
Badge Number: 4
CA Department of Transportation
1120 N Street
P0 Box 942673
Sacramento, CA 94273-0001
Phone: 916-6544438
FAX: 916-654-6608

Thomas C. Werner
Badge Number: 31
New York State DOT
1220 Washington Avenue
Albany, NY 12232
Phone: 518457-6438
FAX:

Y.B. Yim
Badge Number: 48
UC Berkeley ITS/PATH
109 Mclaughlin
UC Berkeley, CA 94706
Phone: 510-231-5602
FAX: 510-231-5600

APPENDIX C

SECOND WORKSHOP ATTENDEES

APPENDIX C

SECOND WORKSHOP ATTENDEES

1	William Stevens	MITRE
2	John Harding	MITRE
3	Rodney Lay	MITRE
4	Stephen Bahier	FHWA-Minnesota Division
5	Ray Starr	MN/DOT
6	Linda Dolen	MN/DOT
7	Glen Carison	MN/DOT
8	Richard Lanu	MN/DOT
9	Richard Braun	BATTELLE-BRW
10	Joseph Sussman	BATTELLE-BRW
11	Thomas Stout	BATTELLE-BRW
12	Jerry Pittenger	BATTELLE-BRW
13	John Herridge	BATTELLE-BRW
14	Chris Clueft	BATTELLE-BRW
15	Steve Nelson	BATTELLE-BRW
16	Dick Lies	BATTELLE-BRW
17	Jeff Benson	BATTELLE-BRW
18	Doug Differt	BATTELLE-BRW
19	Paul Hoffman	BATTELLE-BRW
20	Dave Bruggeman	BATTELLE-BRW
21	Cheryl Mcconnell	BATTELLE-BRW
22	Howard Preston	BATTELLE-BRW
23	Jeff Holstein	BATTELLE-BRW
24	Jeff Ottesen	BATTELLE-BRW
25	Bill Troe	BATTELLE-BRW

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9. Anwar, M. and Jovanis, P. "Assessing the Safety Benefits of Automated Freeways," for PATH, University of California-Davis, UCB-ITS-PRR-93-29, December 1993.

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