Precursor Systems Analyses of Automated Highway Systems

RESOURCE MATERIALS

AHS Roadway Deployment Analysis

U.S. Department of Transportation
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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 a multi-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
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and Development

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16. Abstract

Deployment of an AHS will require a comprehensive analysis of the facilities contemplated for installation or modification to determine the most appropriate means of implementation. Two basic operational environments, rural and urban, have certain distinguishing features which will affect their implementation strategy. In some cases, urban environments will interface with rural environments, such as a linkage between cities at the city fringe. The significance of these differences is exemplified by considering the rural environment as an intercity linkage. This deployment may involve land acquisition in a rural environment. The land use requirements, cost of land, social and transportation system disruptions of the deployment and implementation processes are expected to be radically different than those considered in an urban area. Perhaps it will be found that there are only certain circumstances in which urban AHS deployment can be reasonably considered as a result of cost or other impacts, requiring the AHS to be feasible only if it can be confined within existing right-of-way. If that is found to be the case, the next step would be to then evaluate the impacts of an AHS confined within an existing right-of-way, and identification of other conditions (cost, environment, noise, schedule, traffic impact, constructability) which may affect deployment. This task will evaluate the application of AHS design concepts to generic and real-world situations that would result in an operational system with minimum negative deployment impacts. Physicai conditions such as lanes, how these travel ways interact with adjacent freeway lanes, and how do such travel ways provide access to other travel ways at junctions will be considered. Conceptual level illustrations of what the AHS looks like as it interfaces with other transportation modes and facilities will be required.

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EXECUTIVE SUMMARY

Objective and Scope

Depending on the particular automated highway system (AHS) concept/configuration selected, it was anticipated that the roadway deployment impacts could range from moderately extensive to practically prohibitive. The objective of the efforts of this activity area was to identify the specific issues, risks, and impacts that should be expected in the deployment of representative AHSs. The goal of the effort was to use the results of this analysis as the basis for formulating recommendations for mitigating any negative impacts identified and maximize the opportunity for successful AHS deployment.

The scope of this analysis included looking at the program team's selected set of representative system configurations (RSCs) primarily in the urban and rural environments. Some consideration was also given to urban fringe and small population centers in rural areas. Aspects of special interest included highway construction impacts, spatial/geometric issues pertinent to freeway design, and infrastructure impacts.

Activity area H was one of eight activity areas analyzed by the program team. Results of activity area H, along with those from activity area A, provided the highway design foundation/perspective for the overall effort. The basis for the area H input included not only the extensive pertinent expertise of the area H team, but input obtained from 1) engineers and planners from the Department of Transportation in Arizona, Texas, and Minnesota, and a national workshop of transportation professionals; and 2) other interested parties and stakeholders.

Methodology

The two major tasks utilized in reaching the objectives of activity area H were to 1) initially define and analyze candidate urban and rural linkages on a *generic* roadway and then 2) review the candidate RSCs against *actual* field sites. The overall approach involved five steps as follows:

1. Identification of issues.
2. Generic analysis.
3. State DOT input.
4. Specific site analysis.
5. Evolution of strategies.

The identification of issues focused on three categories of the physical roadway and its associated characteristics.

1. Spatial requirements—e.g.,

   · AHS lane locations and dimension.

- Shoulders.
- Right of way.
- Entry/exit facilities.
- Frontage roads.
- Barriers.

2. Infrastructure—e.g.,

   - Instrumentation.
   - Pavement.
   - Drainage.
   - Communications plant.
   - Traffic operations centers.

3. Construction

   - Constructability.
   - Cost.
   - Conversion strategies.
   - Connectivity with other facilities.
   - Termination of AHS facilities.

The details considered included preferred locations of AHS lanes (e.g., on the inside of the freeway), possible conversion of existing high occupancy vehicle (HOV) lanes, grading separated lanes where spatial restrictions are severe, using different types of barriers, special requirements (e.g., use of shoulders to facilitate maintenance and snow storage), and drainage requirements. AHS application to generic roadways was considered to determine if typical roadway features would be likely to dictate compromises in AHS design concepts and/or to impact negatively on the safety and capacity goals for AHS facilities. Subsequent evaluation of selected AHS concepts against actual field sites was performed to look for *real world* impacts of a proposed deployment that might escape exposure when reviewed only in relation to generic settings.

The culmination of these efforts was 1) formulation of findings regarding the potential deployment impacts of selected RSCs (i.e., AHS configurations) and 2) generation of recommendations for ways to enhance the AHS deployment process.

Results

Activity area H identified and analyzed the issues, risks, and impacts of deploying an AHS using various RSCs in rural and urban environments. The key findings from this analysis follow. Additional findings and supporting material are presented in the main topical report for area H.

<u>Spatial Needs</u>

Some AHS concepts will require extensive roadway and structure reconstruction. Costs to deploy an AHS vary widely depending on whether it's simply a matter of converting an existing lane or doing a massive upgrade to add lanes and require widening bridges, upgrading interchanges, and upgrading intersecting arterials. Examples of both these approaches are presented in the area H report. One of the relatively straightforward lane conversion type examples identified involved costs on the order of $3.6 million per mile. One of the relatively complex examples (i.e., adding lanes to a 22 km section of I-494) costs $41.0 million per mile. Concepts that call for exclusive AHS lanes, connected to exclusive AHS ramps, and separated from non-AHS lanes by physical barriers, might find the highest level of implementation success on existing freeways with compatible existing HOV systems. This is true because most of the space required and the associated general lane configurations would already be in place. Likely adverse public reaction to taking away HOV space for AHS use might be addressed by promoting the benefits of AHS and/or giving HOV preferential treatment in access or usage charges. Additional lanes intended to serve AHS in a rural environment may not be cost effective for long distances, requiring consideration of a mixed flow AHS concept.

Deployment Evolution

AHS deployment evolution may consider a limited focus on mixed flow rural applications at first as a means of developing and field verifying the control and vehicle technology. The mixed flow concept will provide researchers and product developers an opportunity to refine mixed flow techniques, as well as offer an opportunity for AHS technologies such as collision avoidance and vehicle positioning to be beneficial to off-AHS systems.

Urban areas have the most to gain from successful AHS deployment. It would be desirable for early successful deployment sites to be identified from feasible urban sites as a means of testing and promoting exclusive-lane AHS configurations.

Transition Lanes

Concepts that call for exclusive AHS lanes plus a transition lane must be carefully reviewed on a case-by-case basis due to the need for additional width of the freeway. Costs are anticipated to rise dramatically in urban areas where additional right-of-way is required to satisfy additional space requirements. Elevated sections may be a viable, albeit costly, alternative in some locations.

Traffic Control Devices

Traffic control devices should play a significant role in AHS deployment, as a means of 1) clarifying right-of-way assignment, 2) providing information regarding states of special operating procedures, and 3) indicating to drivers which lanes are available for AHS use. Application of traffic control devices must be consistent nationally among all AHS concepts to promote the highest level of driver understanding and predictive reaction.

Pavement Design

Pavement for AHS lanes and shoulders should be more durable and require less maintenance and repair than standard freeway pavement to allow maximum use of the lane with minimal downtime. Sensors built into the pavement would assist system monitors in evaluating surface conditions and pavement deterioration conditions.

Unique Environments

The deployment of an AHS is unique to each environment. Design generalizations should be avoided. Each application should be evaluated individually for factors such as bridge and drainage structures, ramp systems, cross slopes, and spatial availability.

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

The objective of this analysis is to identify the issues and risks related to the deployment of the automated highway system (AHS) in urban and rural operating environments, from the perspective of impacts on the roadway for each of the representative system configurations (RSC).

The purpose of this effort is to identify and evaluate the various issues and risks and to determine if a mitigation strategy can be identified that addresses the negative implications to a level that makes AHS deployment successful in a variety of operating environments when applied to the RSCs.

This report addresses the following areas:

- Operating environments inclusive of an urban area, rural area, small population center in a rural area, and an urban fringe area.
- Issues associated with the spatial requirements of AHS.
- Impacts of AHS deployments on existing facilities.
- Issues associated with infrastructure needs and impacts of AHS.
- Alternative construction strategies.
- Construction administration issues.
- Land use, traffic and cost impacts.
- Application of RSCs to real life scenarios.

The report reflects input from State Department of Transportation (DOT) participants as future stakeholders in AHS.

Analysis Approach

The analysis approach consisted of four primary areas, each discussed in detail below:

- Identification of issues.
- Generic analysis.
- State DOT input.
- Specific site analyses.

Identification of Issues

A list of potential issues was developed by reviewing the genesis of how freeways are constructed and attempting to evaluate how the RSCs would "fit" into standard freeway design techniques. The base reference for this effort was the American Association of State Highway and Transportation Officials' document, *A Policy on Geometric Design of Highways and Streets*, regarded as the guiding criteria for freeway design in the United States. Supplemental data was obtained from the established freeway design standards of three State DOTs. It soon became obvious that although there were direct impacts of AHS in terms of standard freeway design techniques, innovative designs would be required in some cases, causing the analyst to develop new design philosophies. This was especially true in the situation where an existing freeway is constrained by the inability to build more lanes due to geographic limitations.

Upon a review of the list of potential issues, it was determined that three basic categories of issues existed:

- Spatial.
- Infrastructure.
- Construction.

Over the life of this research effort, additional issues were identified through interaction with other interested parties and potential stakeholders via conferences, seminars, and meetings. An Automated Highway Systems workshop was sponsored and held during the Transportation Research Board (TRB) annual conference in Washington, D.C. in January of 1994, allowing individuals interested in the topic to listen to presentations of what an AHS system consists of and how it might function, to participate in open forums, and to provide their perspective on the merits or pitfalls of the AHS concept.

Issues input was also derived from interfacing with other research teams participating in the AHS precursor systems analyses project, university sponsored forums, forums with State DOTs, and forums held in association with Institute of Transportation Engineers (ITE) conferences. Within the research team, interface was developed with other researchers working on urban and rural comparison, safety, malfunction management, and entry/exit analyses.

Some identified issues were already being studied in more detail under other portions of the precursor systems analyses program. The resulting list of issues for investigation represented a wide cross section of input sources and provided a basis for which subjects relative to freeway design merited examination under this effort.

Generic Analysis

The second step of the process was to conduct a detailed evaluation of each identified issue in terms of application to the various RSCs for the four operating environments:

- Rural.
- Fringe.
- Urban.
- Small Population Center in a Rural Area.

During this process, each RSC and operating environment were tested against the issue to determine if there was any impact and, if so, was the impact negative or positive. The assumption at this point was that these issues were to be applied to all freeways in general, not any specific freeway. Thus, an attempt was made to identify all alternatives in terms of all freeway situations so that the analysis would be valid on a national level.

To assist in this process, the research identified the relationship between the issue at hand and standard freeway design criteria as a basis. RSCs were then considered, and conclusions were drawn as to the impact of each RSC.

In the event of a negative impact, the research attempted to identify reasonable mitigations. In some cases, no reasonable mitigations were identified; or the analysis led to the conclusion that further detailed study, beyond the scope of this effort, would be appropriate.

One of the advantages of the time frame of this project was that it allowed the research team to present interim findings of the generic analysis to a senior review team and project managers acting on behalf of FHWA, and to refine the conclusions and direction of the issues analysis prior to final presentation, reflecting a diverse cross section of viewpoints.

State DOT Input

As a means of reflecting the concerns and desires of a major future stakeholder, the project team solicited input from two progressive State DOT agencies. The intent was to introduce the agency's key leadership to the concept of AHS and to gather their perspective on the compatibility of the physical roadway aspects of AHS with the State's freeway design, construction, and maintenance activities. It is possible that the State DOT agency may be the maintaining agency of an AHS system if future maintenance policies are similar to those in place for the existing freeway system.

Workshops were held in which the DOT was given a presentation of the AHS concept and the specific RSCs being developed by this research team. Presentation materials included graphics illustrating the various potential AHS design strategies that were developed based on the generic analysis of the identified issues. DOT participants reacted to each RSC concept and graphic and provided insight into what they saw as potential issues and risks with each. This information was then summarized and considered in further refinement of the generic analysis of issues.

Summaries of these workshops are contained in the appendices of this report.

Specific Site Analyses

The results of the generic analysis of issues were applied to some specific freeway sections identified as having the characteristics associated with each of the four operating environments. The specific sites analyzed included:

- Urban Area—I-10 in Phoenix, Arizona.
- Rural Area—I-10 between Phoenix and Tucson, Arizona.
- Fringe Area—I-394 at the urban fringe of Minneapolis, Minnesota.
- Small Population Center in a Rural Area—I-35 in New Braunfels, Texas.

Although the original project was designed to examine only urban and rural operating environments, it was concluded that there may be some physical differences in a fringe area as interchanges become less frequent and the character of the freeway changes between urban and rural. A similar concept was envisioned for a small population area in a rural operating environment, where a freeway widens to provide additional lanes for a relatively short distance through the population center, then reduces width back to a rural freeway design.

Guiding Assumptions

The following assumptions were identified by FHWA at project initiation and used as general assumptions throughout the course of this project:

1. All vehicle types (automobiles, buses, trucks), although not necessarily intermixed, must be supported in the mature system. Initial deployment emphasis is expected to be on automobiles and vehicles with similar vehicle dynamics and operating characteristics. This research team focused on deployment relative to automobiles, pickup trucks, and small passenger vans.

2. The vehicles will contain instrumentation at various levels of intelligence that will allow the AHS to control the vehicle when it operates on instrumented segments of the roadway, except when deployed as a part of a “pallet” system, which provides a means of transporting the automobile on an intelligent carrying device.

3. Not all vehicles will be instrumented and not all roadways and lanes will be instrumented:

    a. Instrumented vehicles will be able to operate on non-instrumented roadways,

    b. Non-instrumented vehicles will be instrumented on a retrofit basis.

4. Operation on a freeway (as defined by AASHTO) is assumed.

5. The AHS will perform better than today's roadways in all key areas including:

    a. Safety—The AHS will be significantly safer than today. In the absence of malfunctions, the system will be collision-free; and a malfunction management capability will exist that minimizes the number and severity of collisions that occur as a result of any system malfunctions.

    b. Throughput—Significant increase in vehicles per hour per lane.

    c. User Comfort—Smoother ride, with less strain on users and high trust in the system.

    d. Environmental Impact—Reduced fossil fuel consumption and emissions per vehicle mile.

6. The AHS will be practical, affordable, desirable, and user-friendly.

7. The AHS will operate in a wide range of weather conditions typical to that experienced in the continental United States.

8. AHS primary system control and guidance will rely on non-contact electronics-based technology as opposed to mechanical or physical contact techniques. The latter might be part of a backup subsystem if the primary should degrade or fail.

Additional assumptions related to the specific issues of AHS roadway deployment were developed by the research team as the generic analysis progressed in conjunction with the RSC definitions. These assumptions are more logically presented and specified in the following chapter.

REPRESENTATIVE SYSTEM CONFIGURATIONS

For the purpose of this document, the research team considered four primary representative system configurations (RSCs). Detailed descriptions of these RSCs can be found in the AHS precursor systems analyses overview report. Only the characteristics of these RSCs relative to AHS roadway deployment are contained herein.

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.

As the research matured, it was apparent that other configurations were possible; and, in some cases, the generic analysis of issues reviews configurations other than those listed above to determine if any issues or risks associated with them revealed significant data useful to the AHS program.

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.

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.

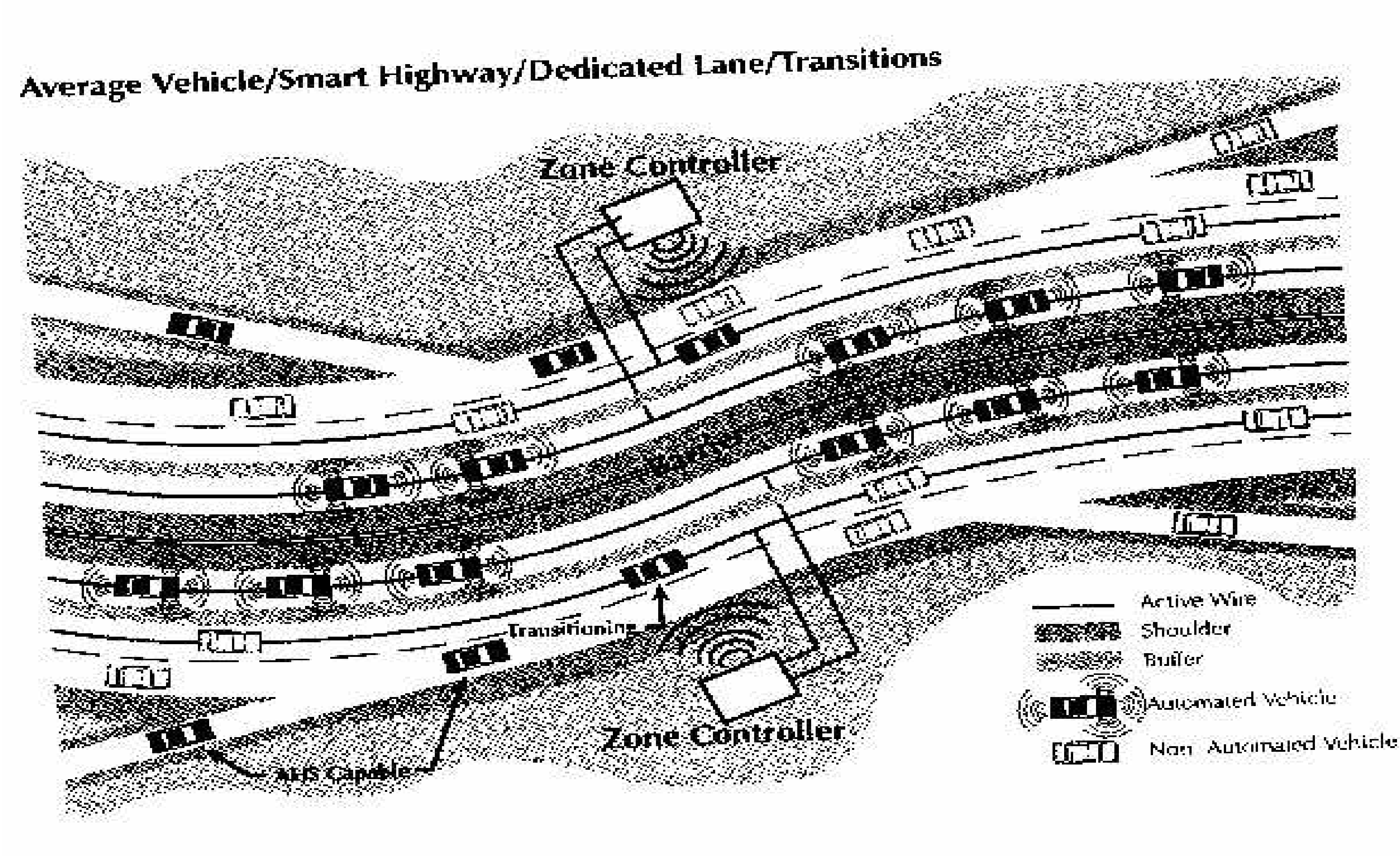
2. Barrier—Physical barrier used to separate AHS and non-AHS traffic streams along the length of the AHS lane.

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

Table 2. Global RSC characteristics.

RSC	Roadway Configuration	AHS Lane Access			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 variation so RSCs addressed in this research. Detailed descriptions of characteristics beyond the roadway deployment characteristics may be found in the AHS precursor systems analyses overview report.


Average Vehicle/Smart Highway/Dedicated Lane/Transitions
Zone Controller
Transitioning
AHS Capable
Zone Controller
Active Wire
Shoulder
Buffer
Automated Vehicle
Non Automated Vehicle

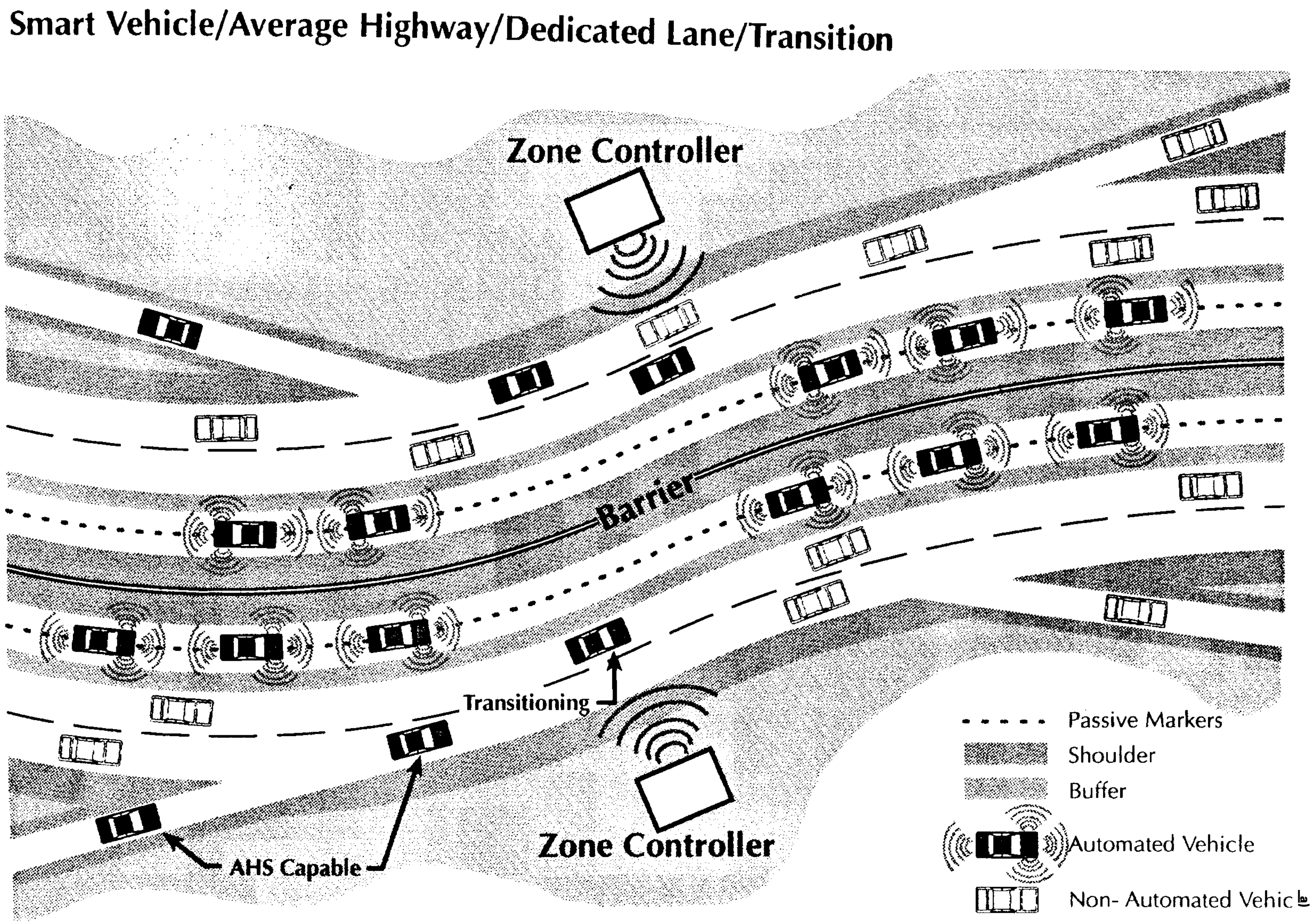


Figure 2. RSC 2A.

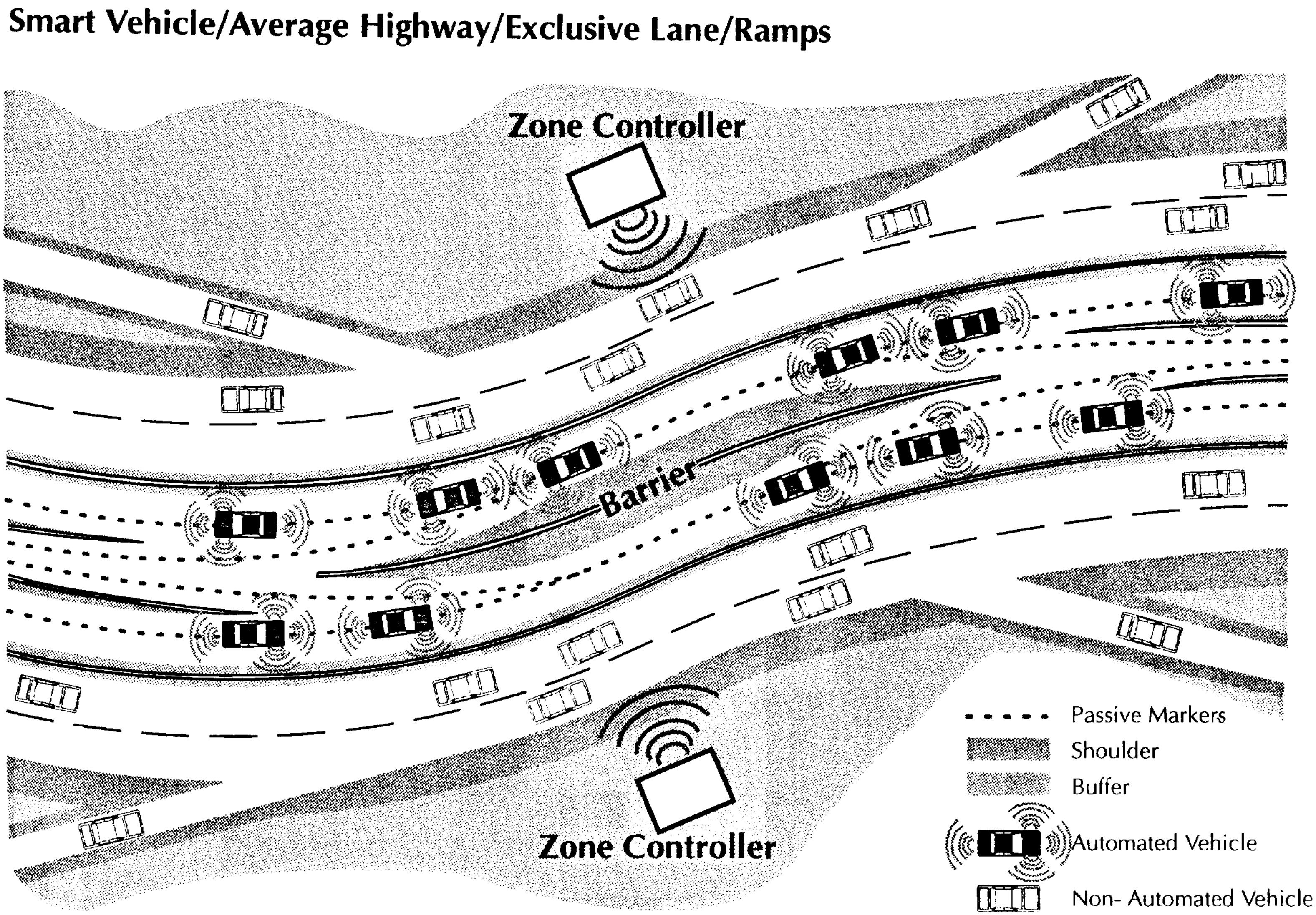


Figure 3. RSC 2B.

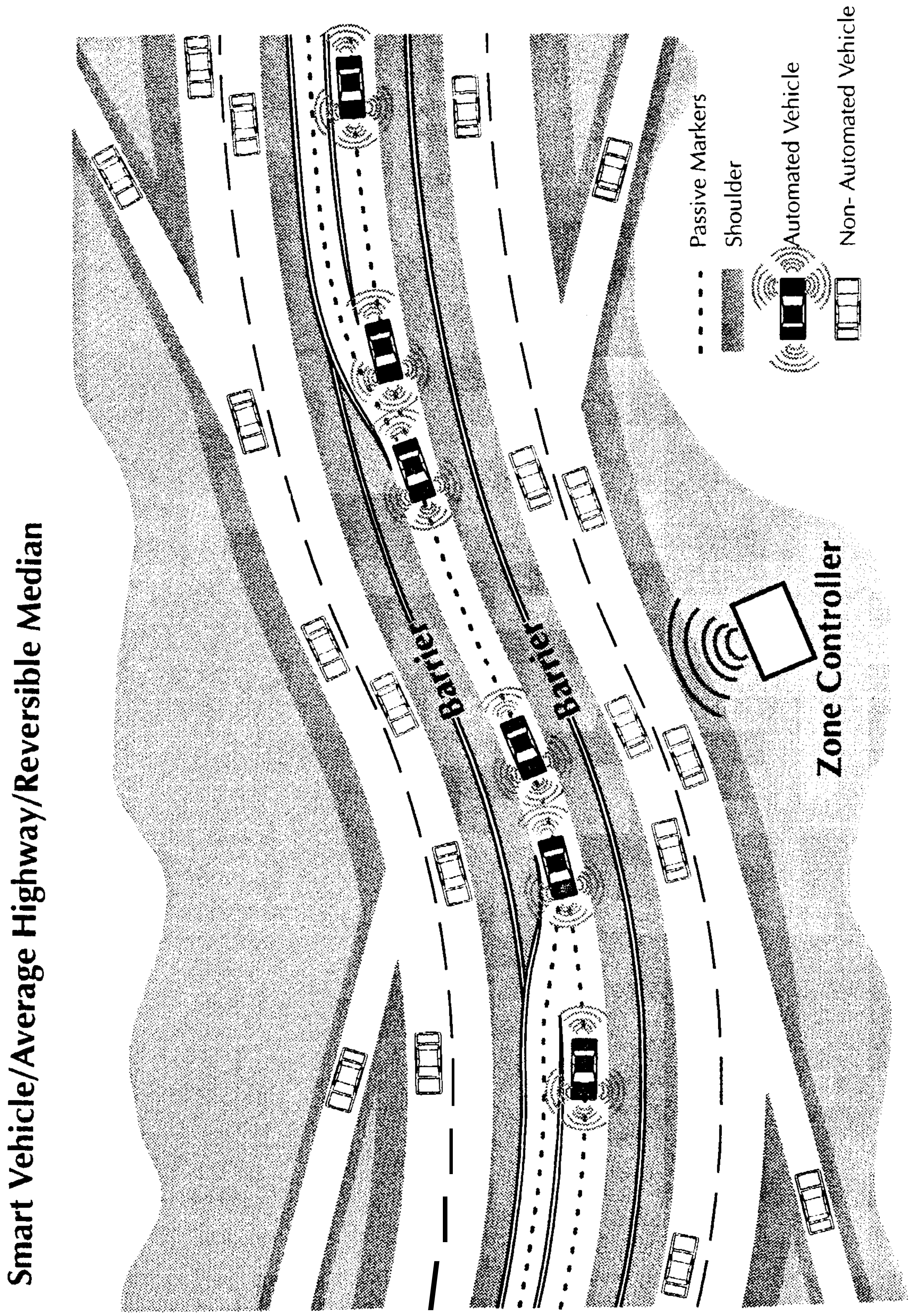


Figure 4. RSC 2C.

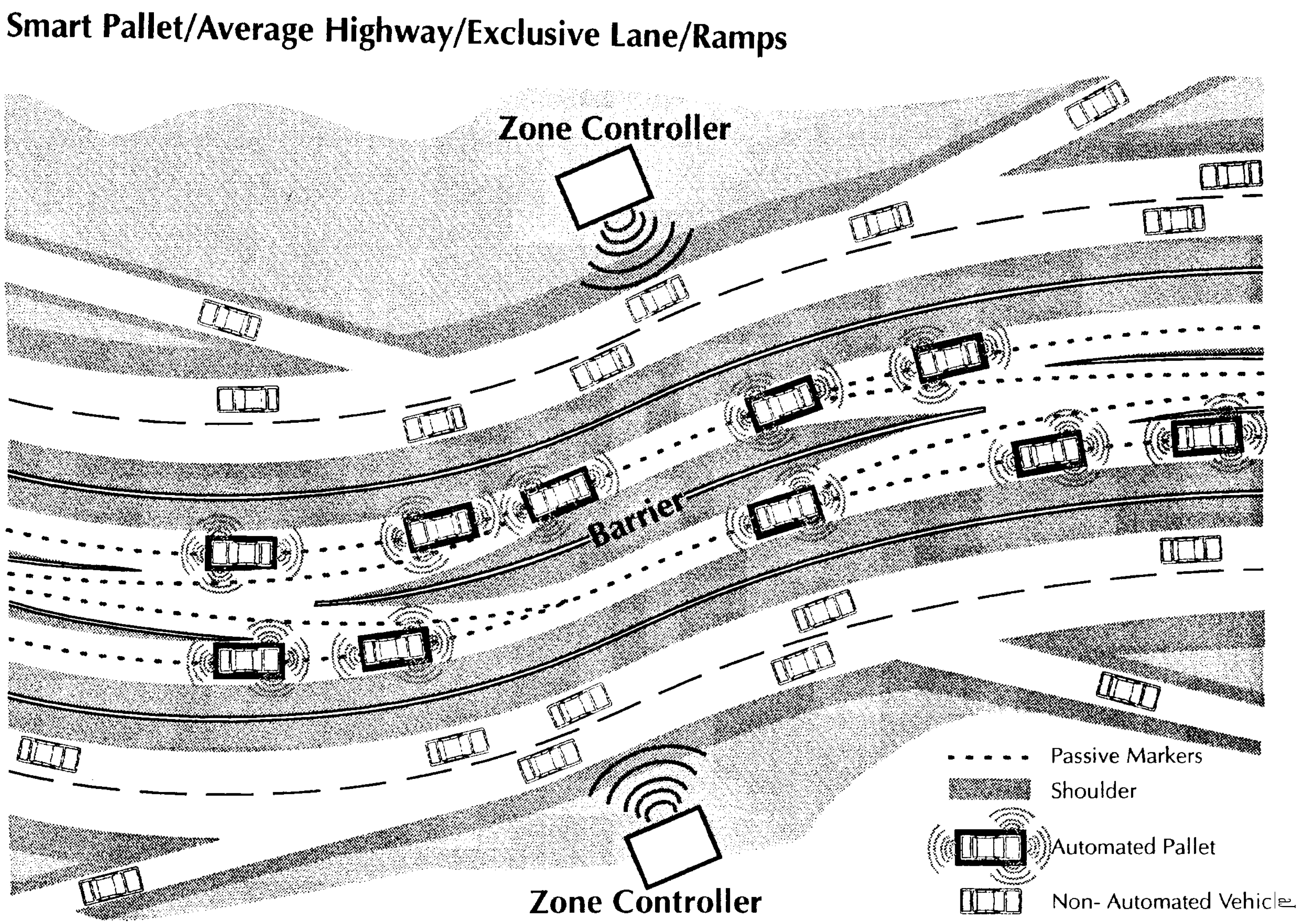


Figure 5. RSC 3.

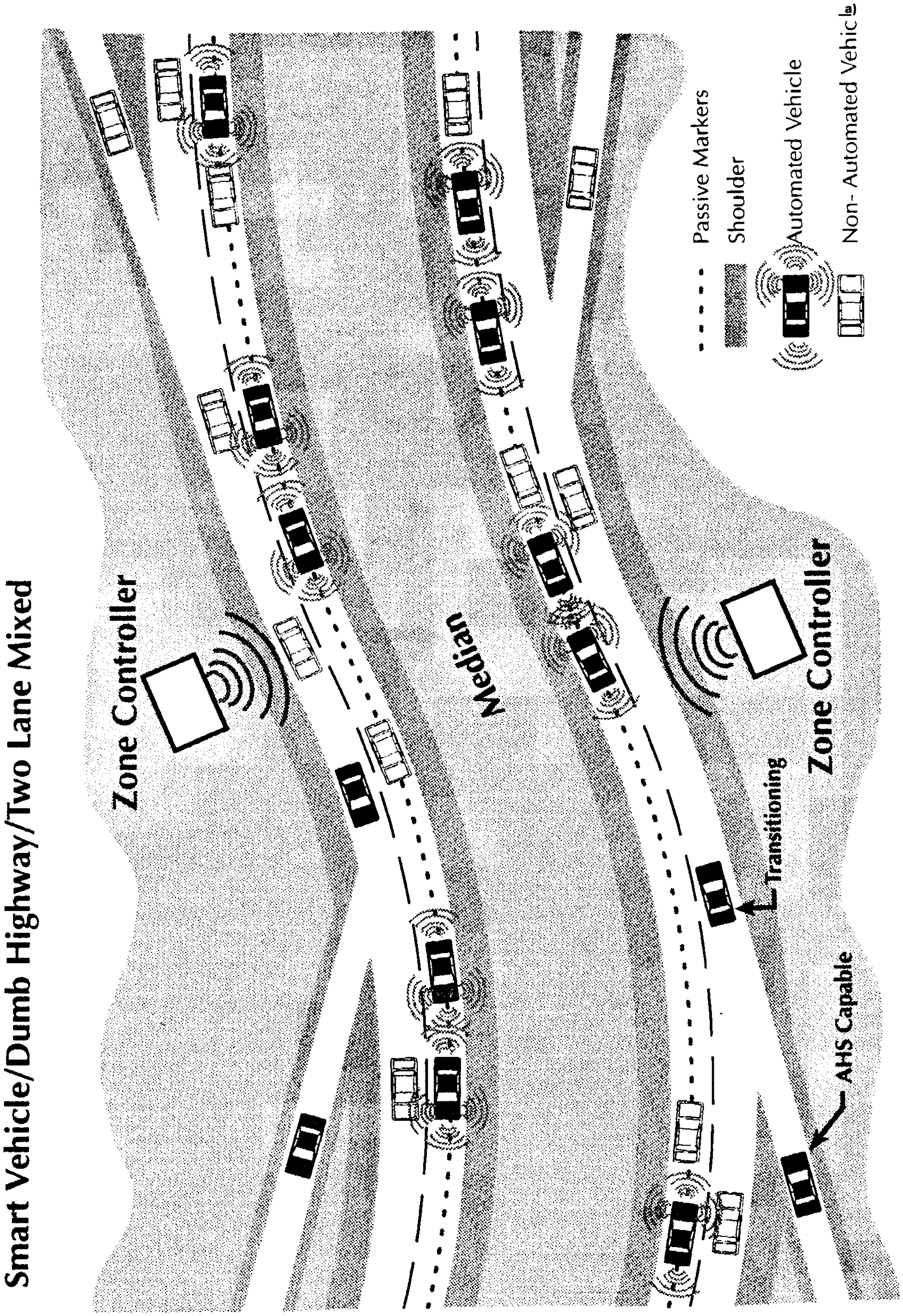


Figure 6. RSC 4.

SPATIAL NEEDS

This section of the report documents the research conducted relative to defining the spatial needs of the AHS and how they may be accommodated on a freeway system. The following topics are explored in this report:

- Lane locations.
- Lane dimensions.
- Shoulders.
- Buffers.
- Barriers.
- Right-of-way.
- Entry/exit connections.
- Transition lanes.
- Frontage roads.

As previously stated, the research is based on deployment of AHS on existing free-ways. Thus, a variety of geometric conditions need to be evaluated relative to lane configurations, typical cross sections, and location and spacing of entry and exit ramps. Figures 7, 8, and 9 on the following pages illustrate some of the features common to typical freeways in the United States.

Lane Locations

Three basic roadway configurations are applicable to AHS design, as illustrated in figure 10:

- Mixed Traffic Lanes—AHS and non-AHS occupy the same lane(s).
- Exclusive AHS Lanes—AHS vehicles have exclusive use of designated lane(s).
- Reversible Exclusive AHS Lanes—AHS vehicles have exclusive use of designated lane(s) with flow directions changing by time of day.

The physical location of any lanes providing exclusive AHS service should be located such that interference from non-AHS traffic is avoided. Based on this assumption, almost all on

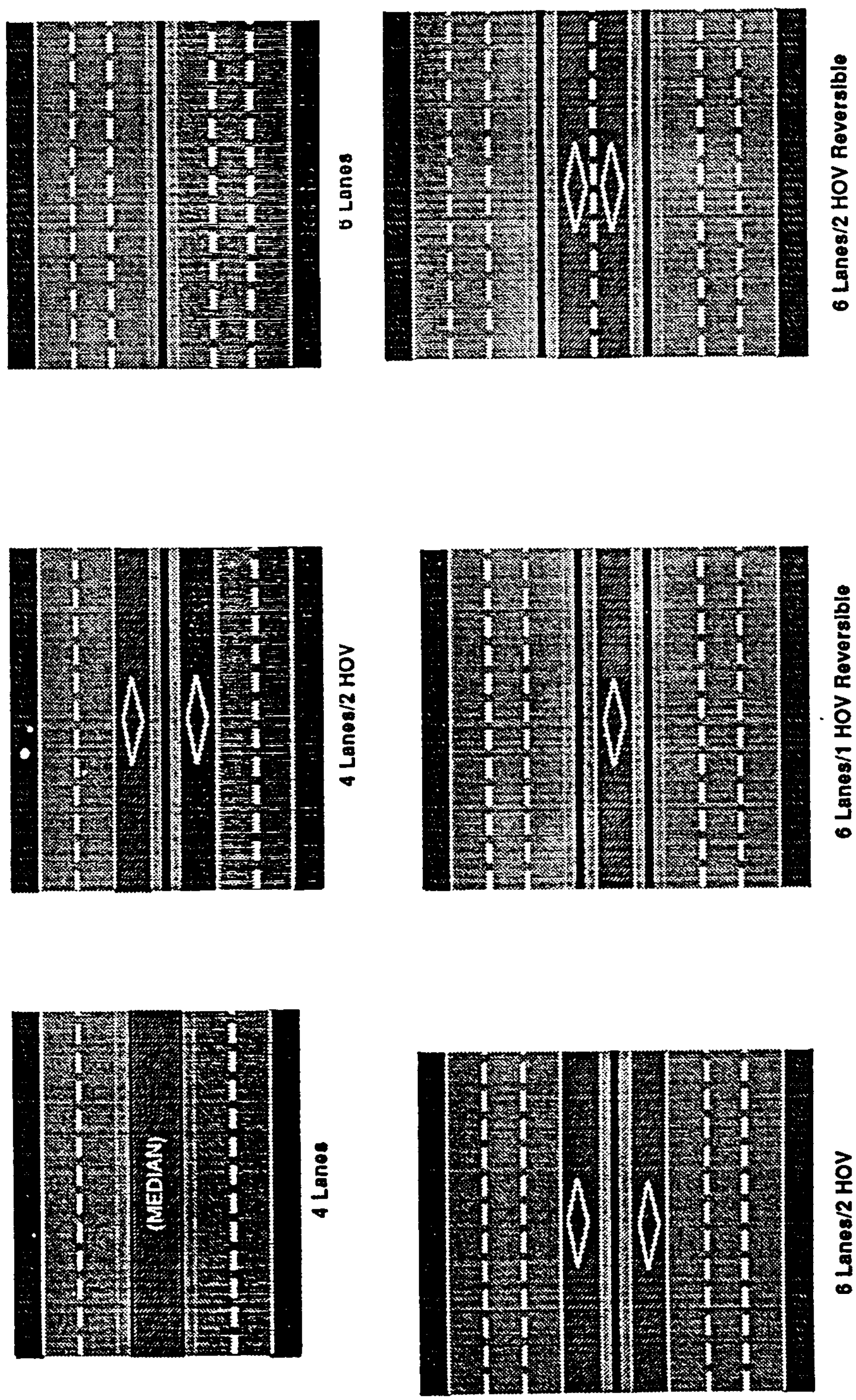


Figure 7. Typical lane configurations.

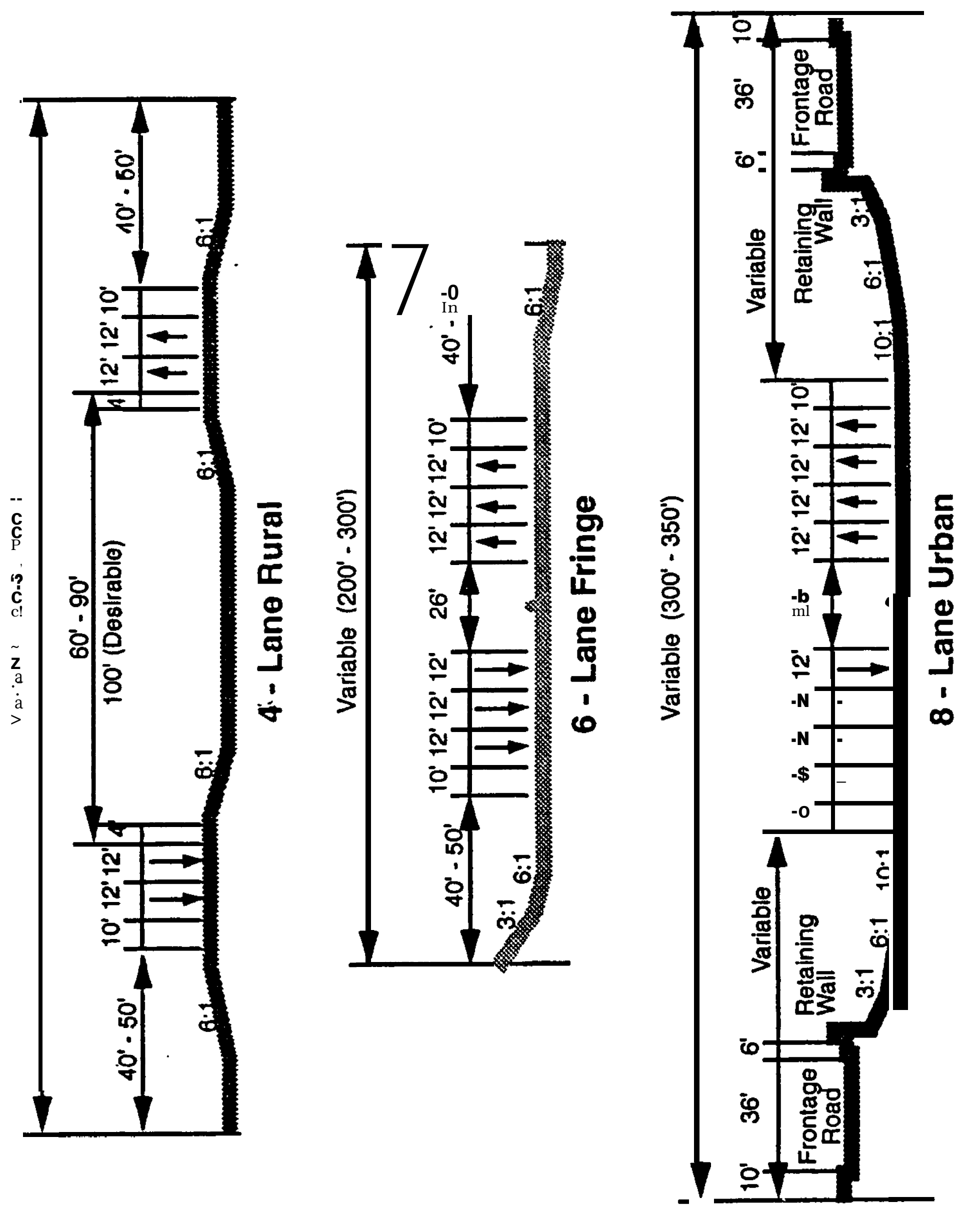


Figure 8. Typical freeway cross sections.

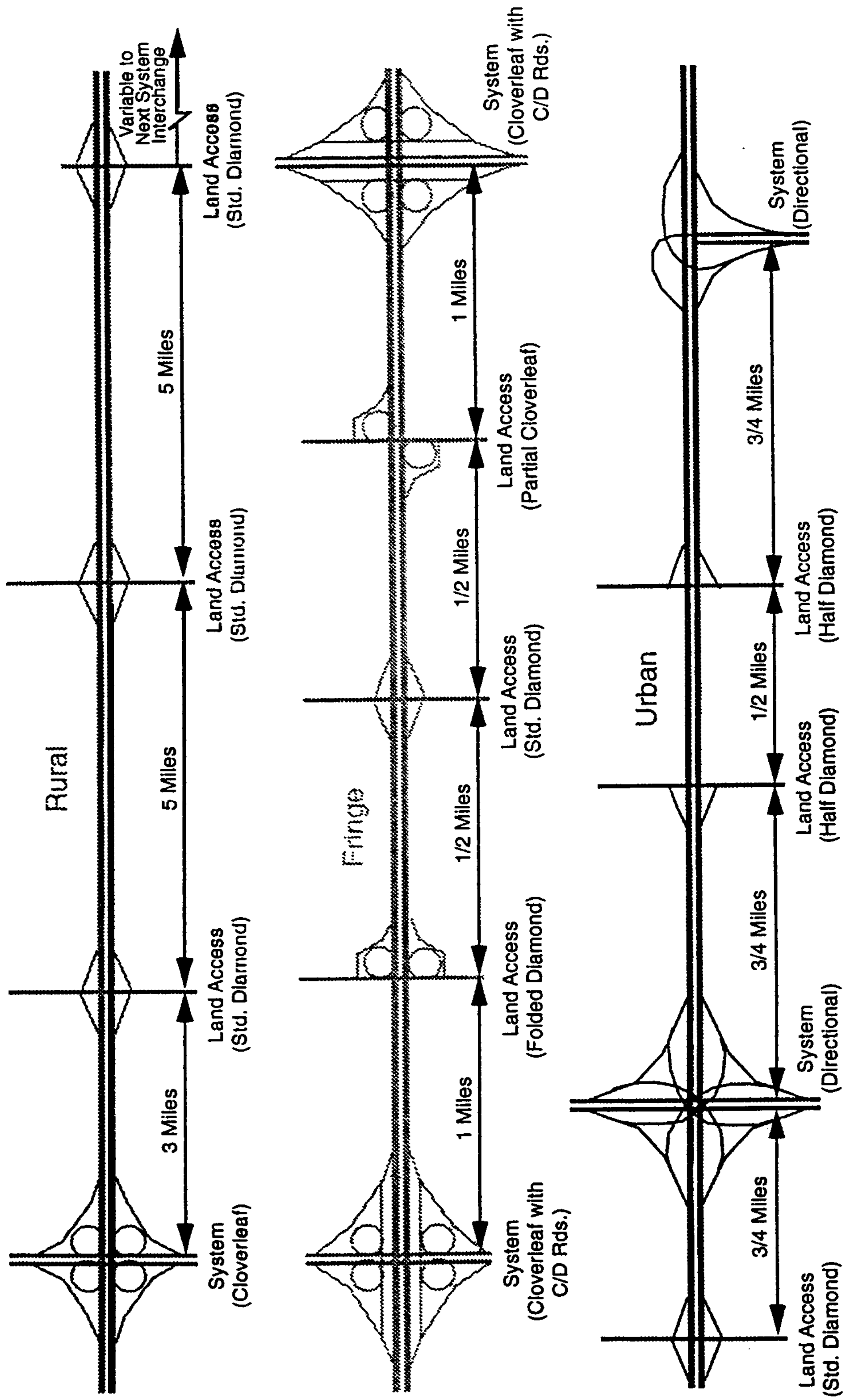


Figure9. Typical freeway interchange configurations and spacing.

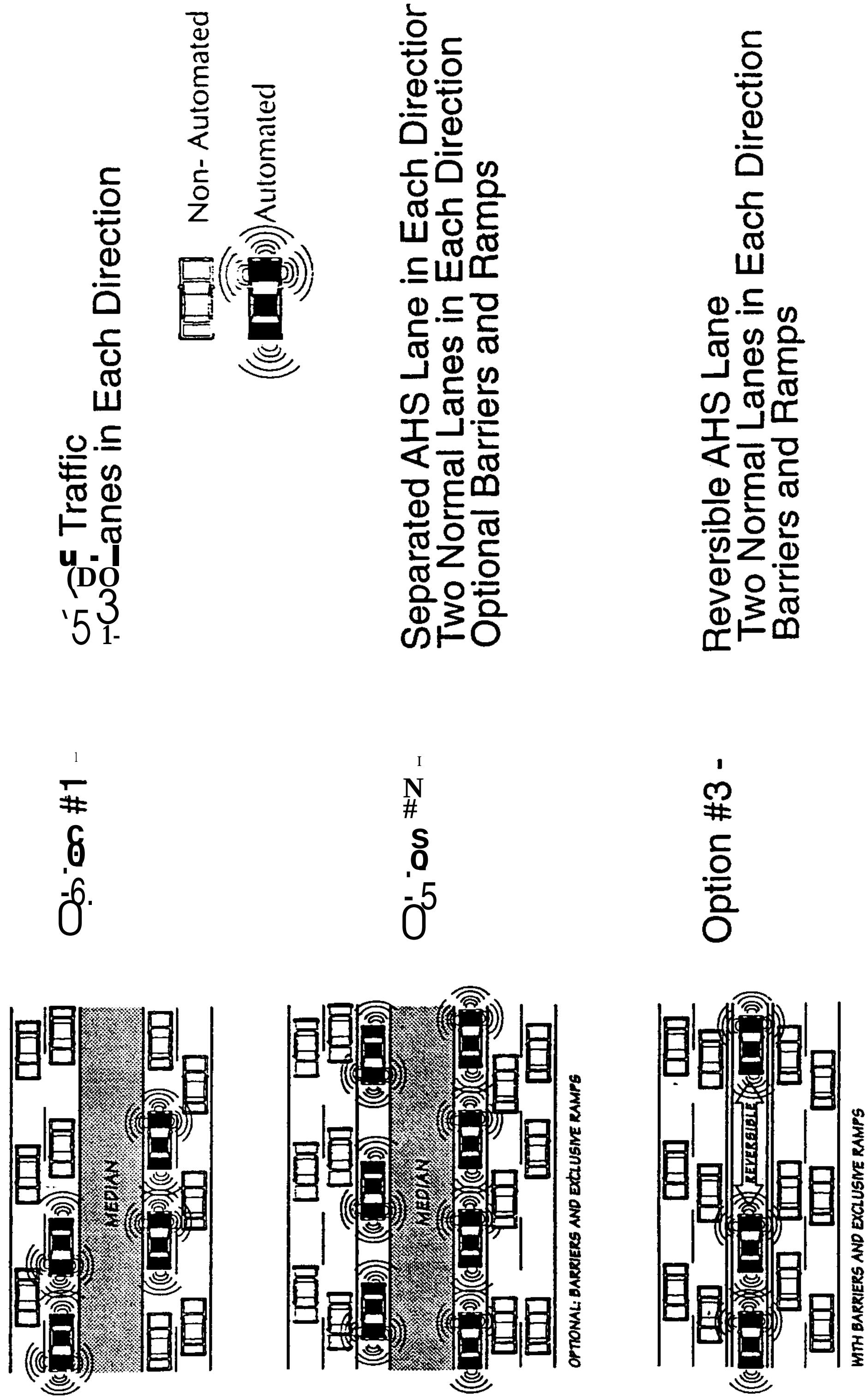


Figure 10. Roadway configurations.

and off-ramp facilities for existing freeways are located on the right side of the freeway, from the driver's perspective, it becomes necessary to locate any special lanes such as exclusive AHS lanes to the left hand side of the freeway.

AHS lanes may be provided by conversion of existing lane space or construction of new lane space as detailed below.

Conversion Strategies

Conversion of an Existing Lane: This concept involves simply reassigning the use of an existing lane to now be reserved only for the exclusive use of AHS vehicles under AHS control. This is a likely option in locations where the construction of new lanes is prohibited for physical reasons or where more than two lanes in each direction exist.

Conversion of an HOV Lane: This concept, similar to conversion of an existing lane, involves the reassignment of an existing HOV lane to exclusive AHS use. Issues related to this concept include the study of HOV lane utilization versus the benefits of AHS operation and assessing all impacts of such a trade off. In some areas HOV lanes are underutilized and application of AHS may provide a higher level of capacity and safety. Special or regular users of HOV lanes may strongly resist this conversion strategy based on the perception of something being taken away from their use if they are not eligible to participate in AHS.

Construction Strategies

Use of Median Space to Construct New Lanes: This concept involves use of existing median space to construct new lanes on the inside of the freeway. Issues related to this method include dealing with physical obstructions such as structures, and drainage features discussed in more detail in the Construction section of this document.

Special Strategies

Reversible Lane: This concept involves either construction or conversion to provide a reversible lane (or lanes) in the median area. This concept requires one-way directional flows in response to directional demands at various times of day.

Mixed Flow: AHS operations, where AHS and non-AHS vehicles occupy the same lane can be provided in any lane since both types of vehicles may need to make the same maneuvers. The effectiveness of the AHS capacity gains are limited in this scenario, since AHS vehicles must travel at speeds compatible with non-AHS vehicles in the same lanes, but the safety aspects of AHS control could still be provided.

Grade Separation: In severely constrained areas, where conversion of existing lanes or construction of new lanes are prohibited, grade separation is an alternative. Grade separation may include locating AHS system lanes above the existing freeway on elevated lanes, or tunneling under an existing freeway to provide the system below ground. Both options have considerable costs that may be weighed against the alternative of obtaining right-of-way and the social disruption associated with freeway expansion into developed areas. Additional anticipated issues that will need to be addressed on a site by site basis will include the appearance of the structures, incident response methods, and emergency access. Figure 11 illustrates the concept of an elevated AHS.

Operating Environment

In the various operating environments anticipated with AHS deployment, site specific features will dictate the success of each of the above concepts. It is anticipated that urban areas will be the most physically constrained and in some cases politically or socially constrained to the point that the addition of new lanes requiring major roadway widening will be prohibited. In such cases, conversion strategies involving existing space should be reviewed as alternatives. In severe cases of constraint, grade separation may be a third tier alternative to lane conversion.

In the rural operating environment, median space tends to be available for construction of additional lanes and facilities. Land acquisition is expected to be less costly when compared to urban area land costs. However, the cost of providing additional lanes for such long distances between major cities may be weighed against the benefits of utilizing a form of mixed flow within the existing lanes.

Table 3 illustrates the anticipated compatibility of each strategy with the operating environments.

Table 3. Lane location strategy compatibility with operating environments.

Lane Strategy	Operating Environment	
	Urban	Rural
Conversion of Existing Lane	X	
Conversion of HOV Lane	X	
Construct New Lanes		X
Reversible Lane	X	
Mixed Flow	X	X
Grade Separation	X	

RSCs

When applying the above concepts to the subject RSCs, it was determined that by RSC definition, lane locations were fixed, but the strategy by which the lanes were provided or deployed was flexible. Thus, although most RSCs used for this research identified the left lane as the AHS lane, RSC 2C utilized a reversible center lane. All RSCs are compatible with the variety of strategies detailed above, dependant upon operating environment.

Lane Dimensions

The width of the lane space assigned to AHS use depends on the following factors:

Design Vehicle Width: A standard 12-ft lane accommodates standard vehicles found on our freeways today. This width accommodates trucks, cars and transit vehicles adequately. If a special hybrid vehicle or pallet is developed either for general use in the future or specially for AHS system use, the width of the space required to operate this vehicle should respond to vehicle dimensions. Special narrow vehicles allowing 8-ft lanes have been studied by others as a means of reducing the needed lane width so an existing cross section can provide more lanes without constructing additional space.

Accuracy of Lateral Control: The tolerance of a lateral control system for AHS defines the range of wander allowed on the part of the vehicle from a given datum. Assuming the vehicle is to always be centered in the lane, the need for additional space between the left and right edges of the vehicle to the lane edge is symmetrical. However, if the AHS system is intended to provide lateral control that locates AHS vehicles in a variety of locations within certain tolerances, as a means of spreading the axle load over more than one wheel track area for longer pavement life, the lane width must respond to a combination of the design vehicle width and the lateral control tolerances.

Driver Comfort: The element of driver comfort plays a major role in defining today's lane widths. With the high level of automation anticipated in the AHS system when operating in an AHS-exclusive lane, the driver perception element becomes an operation performed by the AHS system, leaving the driver only with the responsibility of accepting system control and having the confidence that the system will safely keep clearance from lateral obstructions and hazards. There may be times when the ability of the driver to take over manual control of an AHS vehicle, under certain emergency scenarios, may dictate a factor in lane width design. In a mixed flow scenario, the AHS driver will provide lateral clearances from other vehicles compatible with today's standards.

Travel Speed: As speeds increase, drivers tend to desire larger clearances from adjacent vehicles and obstructions. AHS speeds are anticipated to be higher than today's standards, where operating conditions allow higher speeds.

Adjacent Features: Lateral obstructions tend to psychologically move vehicles away from the obstruction. As the size of an obstruction increases, drivers tend to move away even more, compared to a smaller lateral obstruction, such as a concrete barrier.

Operating Environment

The width of the AHS lane is sensitive to operating environment only to the extent that if a system is being designed for an existing freeway, constrained from widening to provide additional lane space, narrower than normal lanes may be considered for the AHS system. The use of special AHS vehicles of widths less than those typical of today's fleet will support the use of narrow lanes as a means of gaining spatial economy.

RSCs

The RSCs affect lane widths in the following ways:

- In an exclusive AHS lane (RSCs 1, 2A, 2B, and 2C), widths can be less than 12-ft, based on design vehicle width.

- In a mixed flow (RSC 4), lane widths must respond to the fleet mix, typically 12-ft in width.

- In a pallet configuration (RSC 3), the width must respond to the width of the design vehicle, the pallet, which needs to be at least as wide as the vehicle it is to carry on the system.

Figures 12, 13, 14, and 15 illustrate potential lane configurations and cross sections for each RSC.

Shoulders

Shoulders are provided along a travel lane or group of lanes on one or both sides for the purpose of providing a space for emergency use. The following issues are related to why one may contemplate the use of shoulders.

Emergency Refuge: Shoulders provide an area to safely pull a vehicle out of the traffic stream when disabled or for other reasons, such as field enforcement by highway patrol individuals. This concept would be applicable to AHS for the occasional vehicle failure or a system failure requiring the immediate removal of a vehicle from the normal traffic stream space.

Accident Avoidance: The shoulder serves as an emergency space for maneuvering around an accident which is in the process of occurring or has occurred, leaving debris or vehicles in the normal lane space, requiring rerouting of traffic temporarily onto the shoulder. In AHS, for this concept to be successful, lateral control systems used in the

AHS lanes must also be provided in the shoulders, or the AHS vehicle and system must be capable of a manual transition onto and off of the shoulder area for a successful maneuver.

Additional Capacity: Shoulders can be utilized as additional capacity lanes if adequate width and control infrastructure exists. Concepts that use a lateral positioning infrastructure as a component of the shoulder could be converted to use special application lanes. These lanes could be provided on a regular basis, similar to use of shoulders during peak hours only, or could be used for special events or incident management mitigation plans on an as-needed basis.

Driver Comfort: Similar to the psychology of lane widths discussed previously, a shoulder provides space between the driver and other objects or features, enhancing driver comfort and a feeling of safety. In the AHS system, driver comfort plays only a minor role, as the system is expected to provide a high level of safety by design, eliminating the human reaction to the proximity to adjacent features and obstructions.

Maintenance Area/Snow Storage: Shoulders provide a space for maintenance vehicles to park during emergency maintenance operations as well as provide a natural space for snow storage or facilitate snow removal. In an AHS system, both of these phenomena are anticipated to exist, although maintenance is intended to be minimized by high level design features.

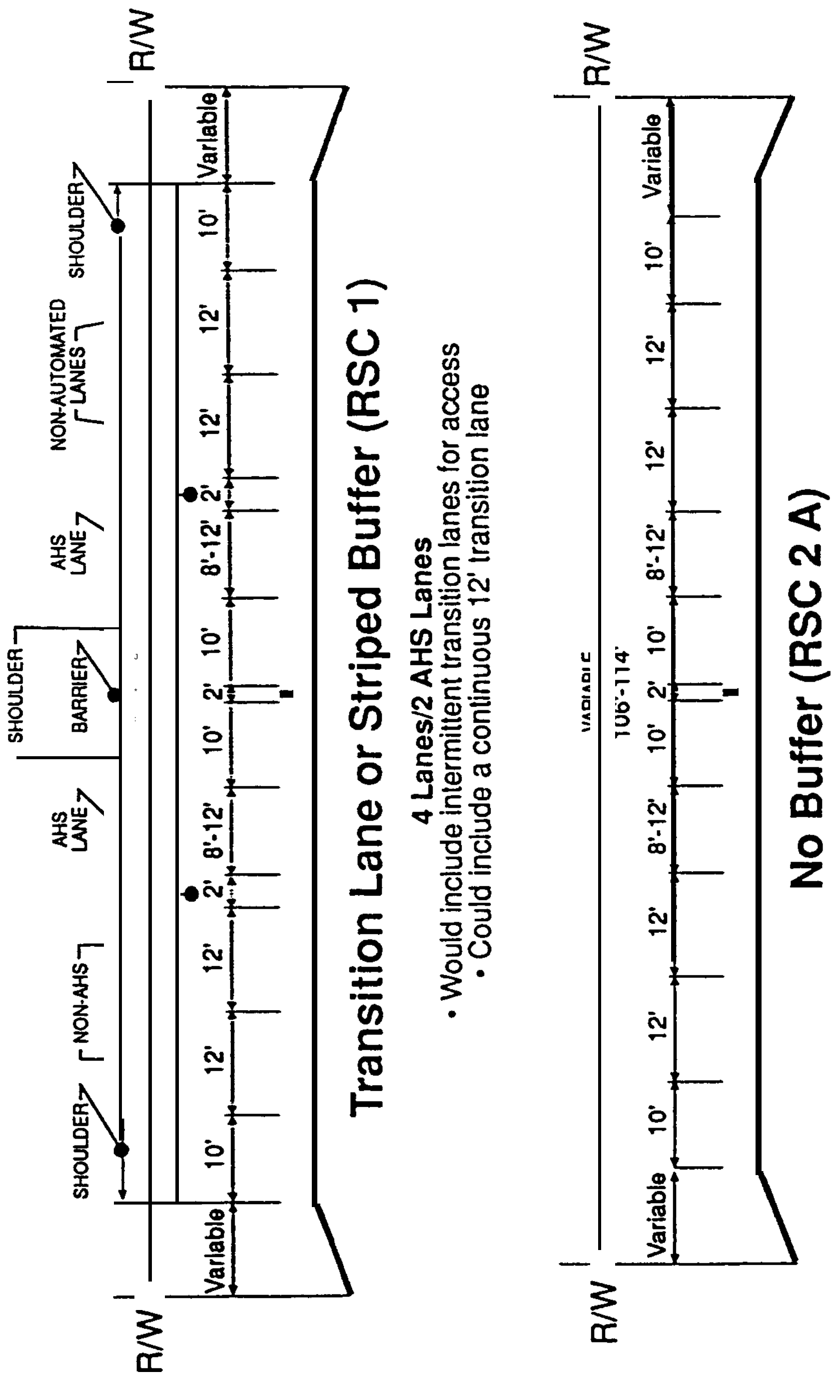


Figure 12. Cross sections, RSCS 1 and 2A.

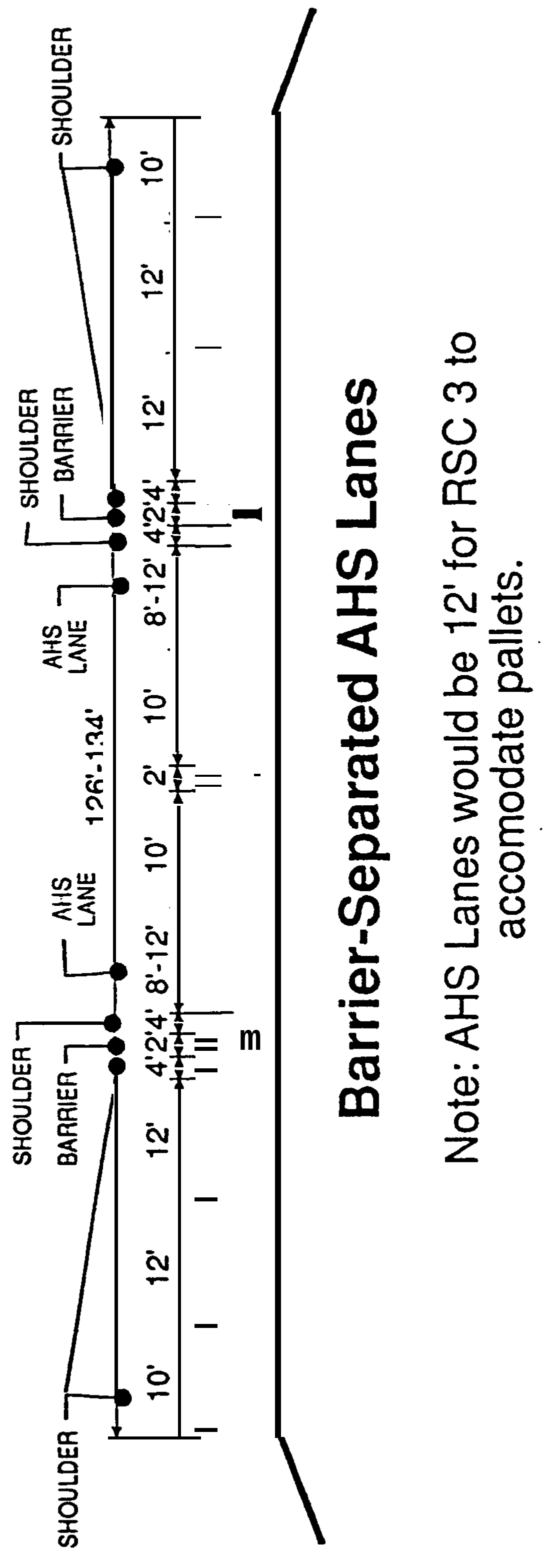


Figure 13. Cross section. RSCS 2B and 3.

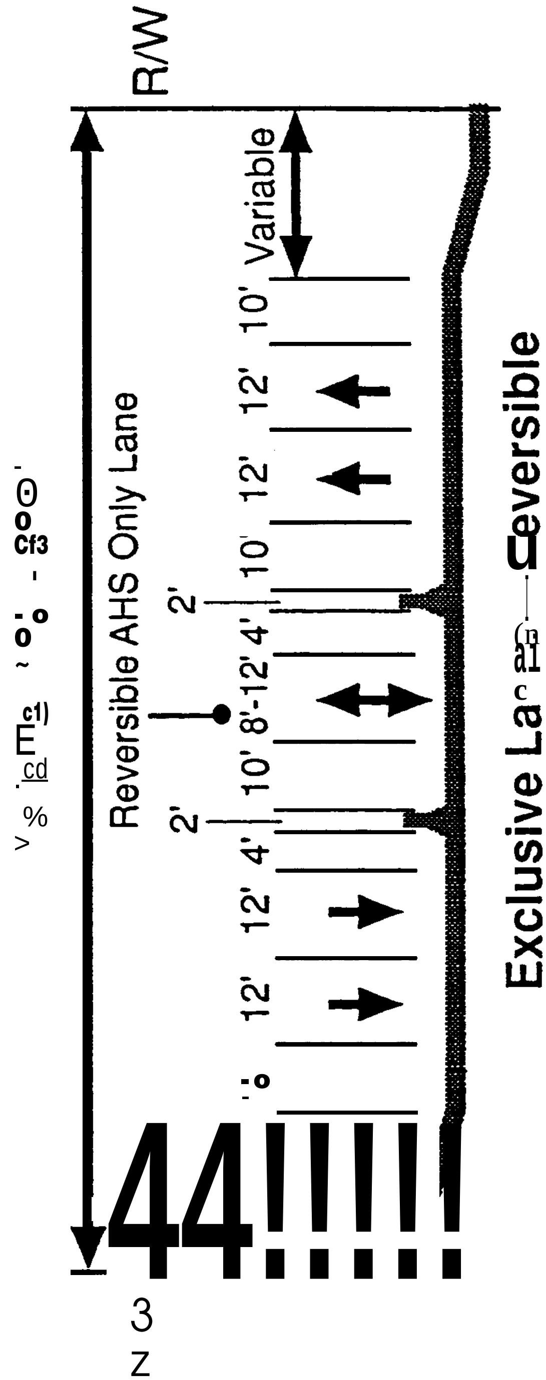


Figure 14. Cross section, RSC 2C.

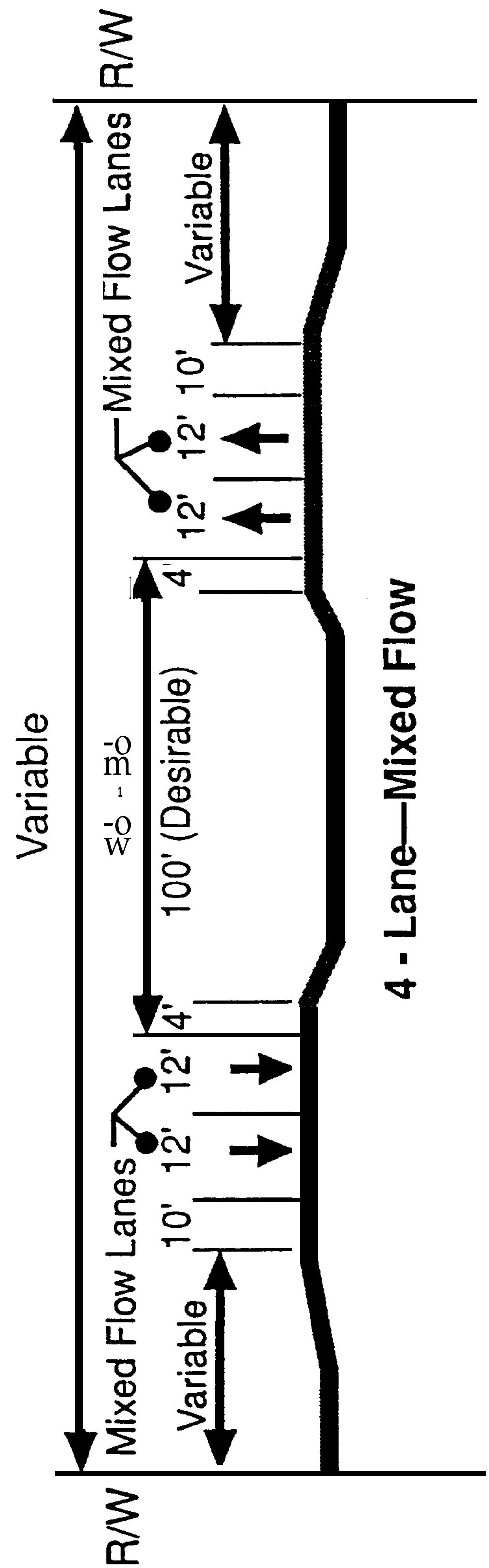


Figure 15. Cross section. RSC 4.

Barrier/Guardrail Clearance: The use of shoulders extends to providing extra clearance between barriers, guardrails and other lateral obstructions by providing a recovery or comfort space between the traffic stream and the obstruction. In an AHS system, the need for a recovery zone is limited by the system's design intent, which is to minimize the driver reaction or driver anticipation element by automating the driving experience.

Drainage: The shoulder area provides a means to minimize pavement breakup by allowing water to be discharged farther from the pavement. The shoulder can also act as a location for drainage inlets and a space where runoff can be routed. In the AHS system, these functions will still play a role. If pavements are made to be snow and ice resistant by some sort of heating/melting technology, the use of shoulders as a drainage participant is even more significant.

The location of shoulders relative to exclusive AHS lanes should be planned for in any deployment of an AHS system. Considering the previous discussion regarding the location of AHS lanes, typically on the left side of a freeway in the exclusive AHS lane configuration, the conclusion may be that a left hand side shoulder would be the most appropriate. However, site conditions may allow the shoulder to be reasonably located on the right side of the AHS lane if that design still provides the drainage and safety characteristics desired.

Shoulder width can range from a minimal width intended only to accommodate drainage and snow storage to a standard shoulder width of 10- to 12-ft. Wider shoulders should be encouraged, where available space allows such design, to enhance the safety aspects provided to disabled vehicles seeking refuge in the shoulder area. The design of shoulders should consider widths sufficient to allow persons to exit a disabled vehicle.

Shoulders should be provided the entire length of an exclusive AHS lane to insure that shoulder space is available to disabled vehicles and incident management to the fullest extent. Consideration may be made of shoulders that exist along only portions of an AHS lane, but limitations of access for those for whom shoulders are intended would be detrimental to the overall AHS system operation in the event of an incident or required maintenance.

Operating Environment

The use of shoulders and their design treatment is sensitive to operating environment only to the extent that adequate space is available for implementation of a full-width shoulder. Availability of space for shoulders is anticipated to be an issue only in the urban operating environment in cases where the freeway section is constrained by external forces or features.

RSCs

For the representative system configurations considered in this research, full-width shoulders on the left side were assumed for RSCs 1, 2A, 2B and 4. RSC 2C, utilizing a reversible lane system in the median of the freeway, the RSC description uses shoulders on both the right and left hand sides. However, only one shoulder needs to be full-width, allowing the other shoulder to be less than full width and serving as a clearance space between the reversible lane and a barrier. RSC 3, which contemplates an exclusive AHS lane separated from the non-AHS lanes through the use of a concrete barrier, uses shoulders on both sides of the AHS lane. As in the reversible lane RSC, only one shoulder requires full-width as a location for accommodating a vehicle that is disabled or using that space for lateral movement.

Buffers

The concept of buffers, as applied to the deployment of an AHS system applies to that space located not at the outside edge of a group of lanes, but rather to a space provided between AHS and non-AHS lanes in an exclusive AHS lane configuration which does not separate AHS lanes from non-AHS lanes with physical barriers.

The purpose of a barrier space is to provide driver comfort for the non-AHS lane adjacent to the AHS lane. In may cases, the AHS lane is expected to have traffic speeds greater than those experienced by the adjacent non-AHS lanes.

The buffer space can also serve as an emergency refuge for either AHS or non-AHS vehicles which have become disabled or for some other reason need to immediately pull to the side of the road. For the non-AHS traffic, this provides the only safe haven on the left side of the freeway, since it could be assumed that non-AHS vehicles penetrating AHS space to get to the left side shoulder would be prohibited due to safety concerns.

The buffer space between AHS and non-AHS traffic streams can range from 2- to 14-ft in width, depending on application, number of lanes, and the need for a non-AHS left side refuge.

In some cases, it is possible to provide a 2-ft buffer space adjacent to the exclusive AHS lane for part of the length, and then widen out and provide a wider space which serves as a shadow to an AHS-exclusive transition lane that is provided for a distance before transitioning back down to the 2-ft width. The transition lane is then used for maneuvers into and out of the AHS lane by AHS-only vehicles.

Operating Environment

The use of buffers and their design treatment is sensitive to operating environment only to the extent that adequate space is available for implementation. Availability of space for buffers is anticipated to be more of an issue in the urban operating environment in cases where the freeway section is constrained by external forces or features.

RSCs

For the representative system configurations considered in this research, buffers on the right side of the AHS lane were assumed for RSCs 1 and 2A. All other configurations include a barrier separation technique, leading to use of shoulders on one or more sides.

Barriers

Barriers, for the sake of this research, are considered to longitudinal, along the freeway lanes. Barriers can take two forms in application. One form of barrier is a perceived barrier which vehicles can penetrate in the event of incidence. An example of a perceived barrier is the use of plastic tubes attached to the roadway surface with epoxy or some other similar chemical or physical connection. The purpose of a perceived barrier is to give drivers a visual clue that the demarcation between two areas is of higher significance than achieved with striping alone.

However, given the nature of the operation of the AHS system and its inherent safety considerations, the perceived barriers are limited in application because they do not provide some of the safety insurance of a positive barrier, and are only slightly more effective than just using striping.

Positive barriers may include devices such as concrete barriers and guardrails. Typically, barriers are used to minimize the severity of potential accidents involving vehicles leaving a roadway where the consequences of striking the barrier are less than leaving the roadway. In AHS applications, the barrier serves the following purposes:

- Contains AHS and non-AHS vehicles in their designated lane areas,
- Enhances safety by prohibiting intrusion of non-AHS vehicles and operators in AHS space through access control,
- Provides a higher level of safety when used to separate opposing high speed flows, typically AHS lanes in a median area, and
- Enhances driver comfort and confidence in the level of safety provided by the AHS system.

Since the design elements of barriers are constantly changing in response to ongoing research, it is wise for the designer to remain current on the state of the art design techniques for barriers and end treatments. One good source of information on this subject is the *AASHTO Roadside Design Guide*.(3)

A major consideration is the space needed to accommodate the installation of barriers. In some cases, barrier installation may mean reducing the available width of an adjacent shoulder or buffer area, or reduction of lane widths as a means for creating adequate space.

As a minimum, positive barriers should be used to separate opposing flow traffic located closer than the AASHTO defined clear zone. Positive barriers are required to separate automated and non-automated lanes to ensure safe operations. Deployments that provide exclusive AHS ramps connected directly to the AHS-only lanes are secured by application of longitudinal barriers as a means of completely segregating automated operations from non-automated operations.

In AHS configurations which provide exclusive AHS lanes, but require the AHS vehicles to negotiate access via mixed flow ramps or to travel across non-AHS lanes to reach the desired ramp systems, the use of barriers may be applicable, but design considerations must be carefully treated.

For example, if one considers a configuration where an exclusive AHS lane is located in the median area and mixed flow ramps on the right side of the freeway, barrier placement would need to allow entry and exit to/from the AHS lane through gaps in the barrier. Such gaps would require careful planning of location and must be long enough to accommodate the lane change maneuver safely. This can be a very tricky proposition in configurations that do not provide and exclusive lane on the right side of the barrier for AHS transition activities because of the difference in travel speeds between the AHS vehicles and non-AHS vehicles. In an urban area during peak traffic times, such a configuration may negatively affect safety and operations because transition maneuvers are limited to specific locations.

During non-peak period when traffic flows may attain ideal speeds, the safety aspects of a longitudinal barrier through which traffic makes lane changes may operate effectively in areas where adjacent lane gaps and travel speeds are compatible, but lane changes are still at fixed locations.

Operating Environment

The aspects barriers provide to AHS operations are applicable in all operating environments. Due to cost considerations, the use of barriers likely makes the most sense in urban areas where congestion is generally at a higher level, possibly encouraging non-AHS intrusion into unprotected AHS lanes.

The use of barriers to separate opposing flows will manifest itself most often in an urban area since most rural freeway sections tend to provide safe separation distances between opposing lanes.

RSCs

In the RSCs examined for this research, the use of barriers is applied in RSCs 2B, 2C and 3 (see figures 13 and 14).

In RSC 2B, an exclusive AHS lane is segregated from the non-AHS lanes by the use of a barrier. This concept assumes a separate ramp system for all AHS maneuvers, making the configuration appear to be two separate roadway systems occupying a common right-of-way with the freeway. AHS ramps can connect from the right or left, as field conditions allow. Non-AHS traffic accesses its non-AHS lanes via standard ramps located on the right side of the freeway.

In RSC 2C, the configuration uses a reversible lane located in the median, protected by barriers located adjacent to both sides of a single AHS lane. This barrier accomplishes the separation of opposing flows as well as the access control aspects. Design of ramp connections needs to consider the opposing flow directions and can be configured from the right or left side.

In RSC 3, the pallet concept, by design, requires a barrier to maintain the required level of access control from non-AHS and non-pallet vehicles. This configuration is very similar to having a transit system located in the median area of a freeway because of the incompatibility of pallet vehicles with other vehicles in the same lane area.

Right-of-Way

One of the biggest problems with spatial accommodation of AHS on an existing freeway is having the space available in which to designate the AHS lane area. In many of the older urban areas, adjacent land uses include established residential, office, and commercial uses built along the frontage of the freeway right-of-way. In some cases, parallel frontage roads encourage certain land uses that can take advantage of the front-age road access or exposure to the traveling public by the location adjacent to a facility on which thousands of drivers pass daily.

Freeways are many times viewed in a negative light by adjacent residential land uses because they represent a physical barrier, similar to if a wall was constructed. Access across this perceived barrier is limited to locations where underpasses or bridge structures exist, and the aesthetics of freeways tend to alienate residents.

In the western portion of the United States, the freeways tend to be newer, and in many cases adjacent right-of-way is undeveloped in some urban and fringe areas. Nationally, most rural settings allow expansion of the freeway within the existing right-of-way because the facility is a four lane freeway in a wide right-of-way.

Considering the challenges of right-of-way acquisition in the urban environment, it is possible that some freeways simply will not have the space available within existing right-of-way, and acquiring adjacent right-of-way may be impractical due to cost, social impact or political reasons.

In such cases, AHS applications may be limited to configurations which utilize a mixed flow concept, require special construction treatments such as elevated lanes, conversion of existing lanes, or reconfiguration of the existing freeway cross section to accommodate AHS facilities.

Right-of-way costs need to be weighed against the alternative treatments in determining if AHS is viable for a specific freeway. The cost of right-of-way is anticipated to be less as one considers sites further from the concentrated urban core into the fringe and rural environments.

Operating Environment

Right-of-way is an operating environment dependant issue only if acquisition is necessary. In such cases, acquisition issues will tend to be more intense and more costly in an urban environment, and decrease as one moves from the urban core to the fringe and then rural setting.

RSCs

In reviewing the RSCs germane to this research, table 4 illustrates the required width for each of the RSC layouts. The width shown is from the outer edges of the outer shoulders. The distance from the freeway to the right-of-way line is variable on both sides of the freeway. The following distances can vary, depending on the use of barriers, buffers, lane widths and shoulder widths in actual field applications.

Table 4. RSC cross section widths.

RSC	Roadway Configuration	Edge to Edge Width
1	3 Lanes Each Direction Exclusive AHS Left Lane	115'
2A	3 Lanes Each Direction Exclusive AHS Left Lane	114'
2B	3 Lanes Each Direction Exclusive AHS Left Lane	134'
2C	2 Non-AHS Lanes Each Direction Exclusive Reversible AHS Lane	112'
3	3 Lanes Each Direction Exclusive AHS Left Lane	134'
4	2 Lanes Each Direction Mixed Flow in Left Lane	176'

It should be noted that the rural width is based on a typical cross section that has a 100-ft area between the two directional lane sets. Most of the urban sections tend to be less for an economy of space.

Typical guidelines in many States recommend right-of-way widths on the order of 325 to 525 ft in width. In heavily developed areas, right-of-way widths of 325 to 450 ft are typical, often times matching the width of a city block.

Entry/Exit Connections

The details of how entry and exit are achieved in an AHS system are addressed under separate research reports on this topic. However, in the context of freeway deployment, ramp locations need to be addressed in terms of how they connect to the freeway system and their relationship with other design features.

As stated in an earlier section of this report, access to the AHS lane can be achieved by any of the following methods:

Relative to AHS lane location:

- To/From the right side.
- To/From the left side.

Ramp Traffic Characteristics:

- Exclusively AHS only
- Mixed Flow with AHS and non-AHS
  - — Separate Lanes
  - — Shared Lane

The presence of longitudinal barriers between the AHS and non-AHS ramps plays a significant role in deciding if the ramp system will connect to the AHS area from the left or right hand side.

In a barrier configuration, the AHS vehicles could access the AHS lanes by:

- Exclusive AHS ramps connected to the right hand side of the AHS lane, requiring elevated structures to carry the vehicles over the non-AHS lanes.
- Mixed flow ramps on the right side with gaps in the barrier for entry/exit maneuvers.
- Exclusive AHS ramps connected to the left hand side of the AHS lane, connecting directly to surface streets via ramps constructed in the median area. In this scenario, traffic demand and traffic signal requirements may require that these interchanges be at locations other than those serving non-AHS traffic to avoid over congestion of the surface street.

In a configuration where no positive barrier is utilized, the AHS vehicles could access the AHS lanes by:

- Exclusive AHS ramps connected to the right hand side of the freeway, requiring a means of securing the ramps from non-AHS use. This strategy could be applied to full conversion of an interchange to AHS-only use.

- Mixed flow ramps on the right side of the freeway. The ramps could have AHS and non-AHS vehicles in the same lane or two lanes could be provided, with one serving only AHS vehicle check-in and check-out processes. Provision of exclusive ramp lanes could be through construction of new lanes or conversion of existing HOV lanes, similar to the concept of conversion of HOV lanes on the freeway as a technique for providing AHS lane space.

- Exclusive AHS ramps connected to the left hand side of the AHS lane, connecting directly to surface streets via ramps constructed in the median area. In this scenario, traffic demand and traffic signal requirements may require that these interchanges be at locations other than those serving non-AHS traffic to avoid over congestion of the surface street. Security from use by non-AHS vehicles is of concern in this application.

Figures 16 and 17 illustrate two concepts for design of on-ramps for system concepts that do not utilize longitudinal barriers. These concepts could also be deployed for systems with longitudinal barriers with entry/exit gaps.

Table 5 illustrates the relationships between flow characteristics, the use of barriers, and geographic location of the ramp systems for standard freeway configurations, where right hand ramps are assumed to connect to the right hand side of the non-AHS lanes, and left hand side ramps are assumed to connect to the left hand side of the left most lane (the AHS lane, in the case of “Exclusive AHS Lane”).

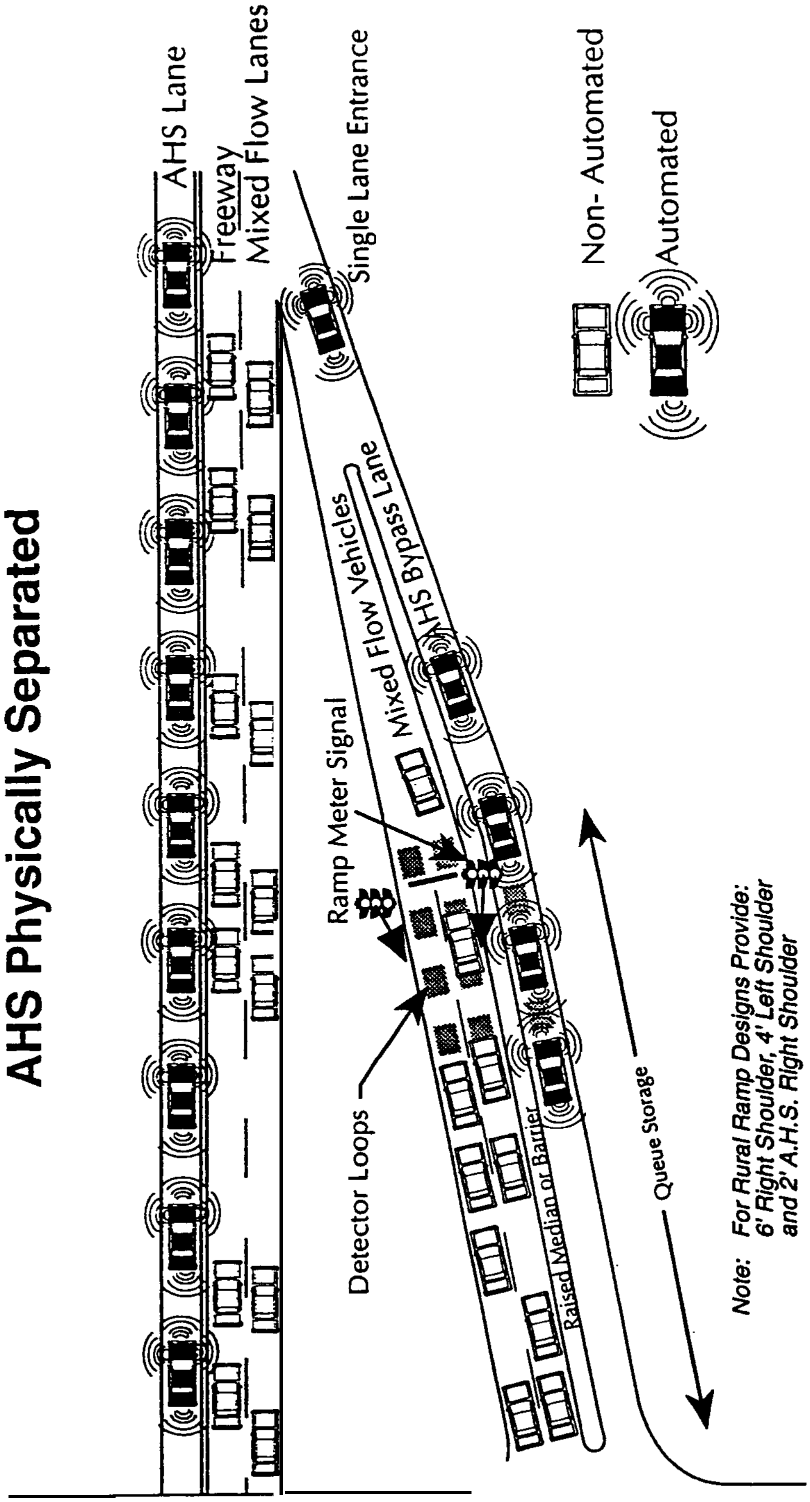


Figure 16. Typical AHS ramp bypass designs—AHS physically separated.

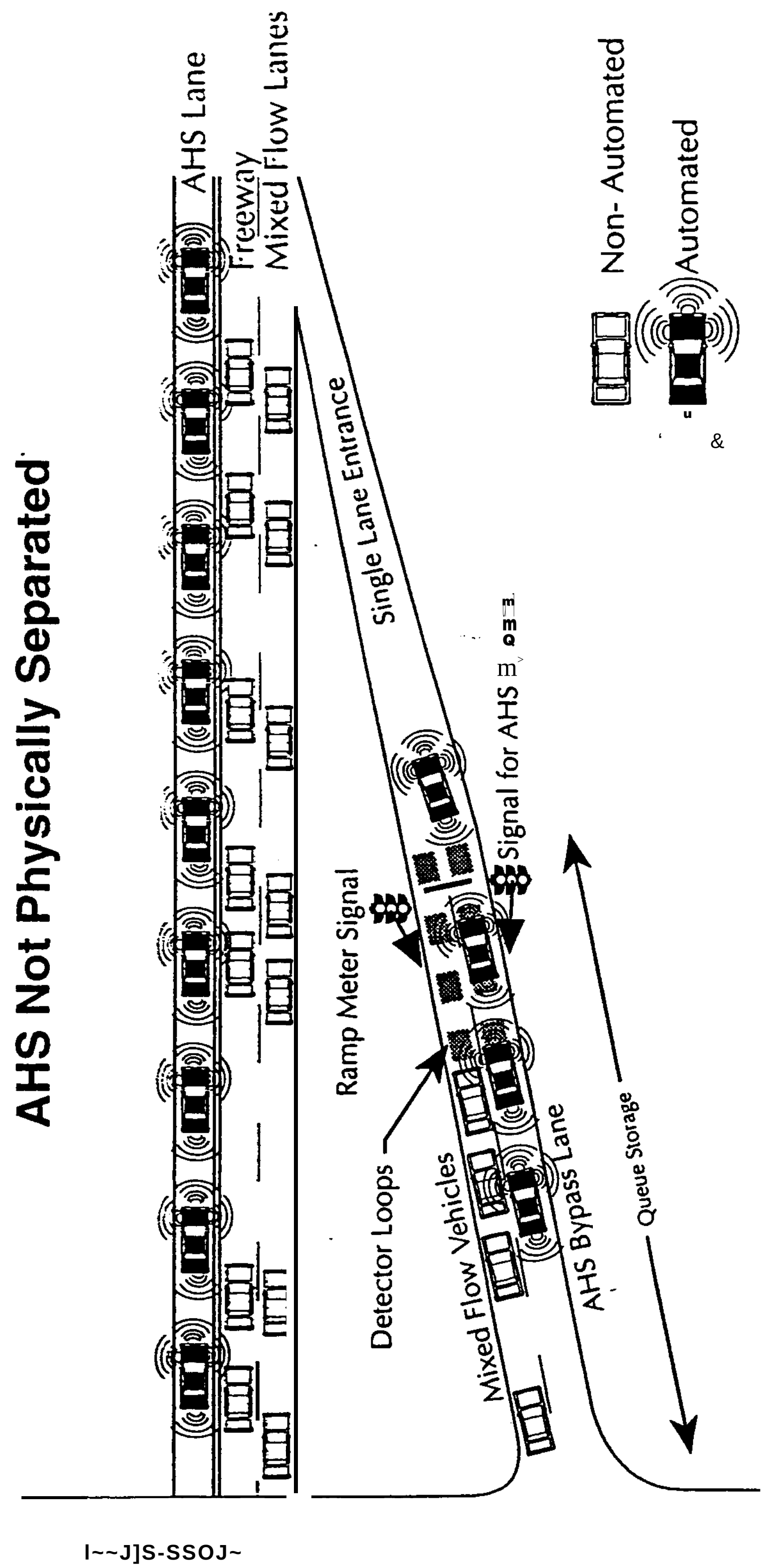


Figure 17. Typical AHS ramp bypass designs—AHS not physically separated.

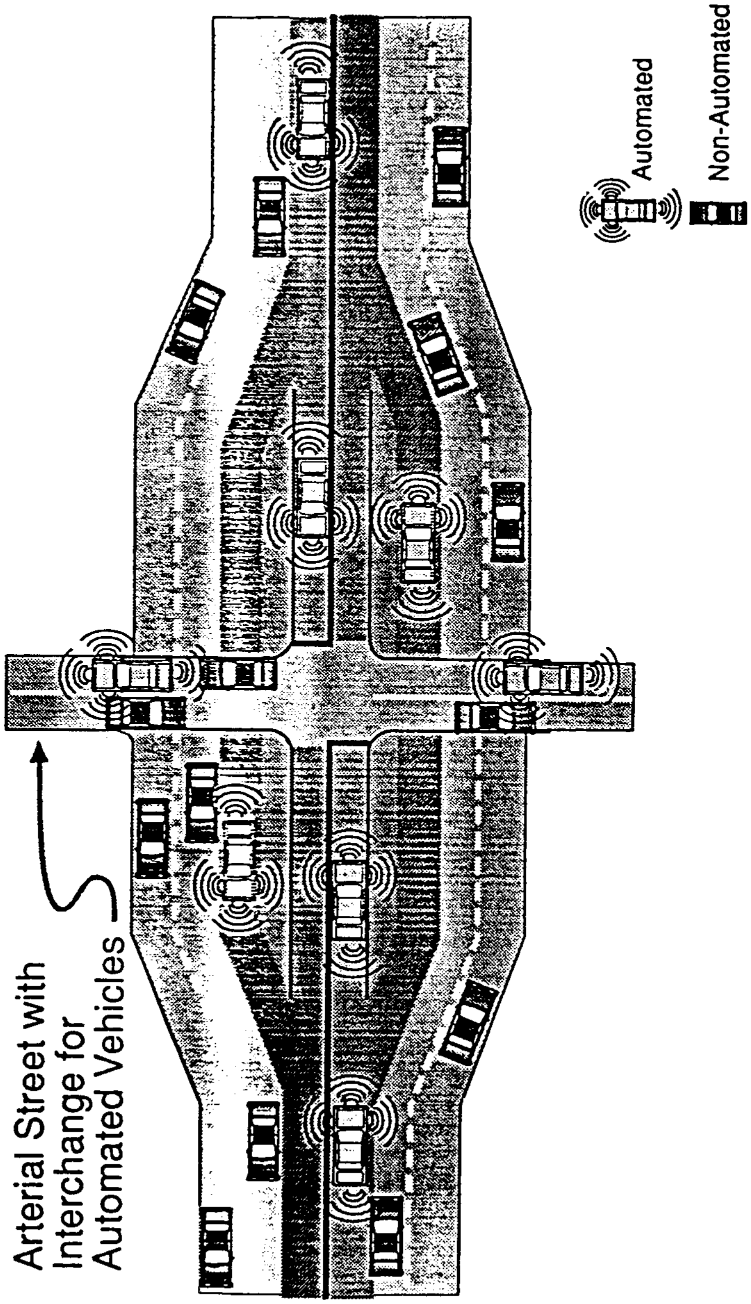


Figure 18. Exclusive entry/exit ramps for automated lanes.

Table 5. AHS entry and exit patterns.

Flow Characteristic	Enter from Right		Enter From Left	
	Exit to Right	Exit to Left	Exit to Right	Exit to Left
Exclusive AHS Lane	Compatible without barriers. Gaps required with barriers.	Compatible without barriers. Gaps required for entry with barriers.	Compatible without barriers. Gaps required for exit with barriers.	Compatible with or without barriers.
Mixed Flow	Compatible	Compatible, but not desirable.	Compatible, but not desirable.	Compatible, but not desirable.

Hybrid alternative designs could be considered which provide direct ramp linkages to an AHS lane with a longitudinal barrier system that does not provide merge and diverge gaps in the barrier. Some configurations, although possible, are not desirable because they violate

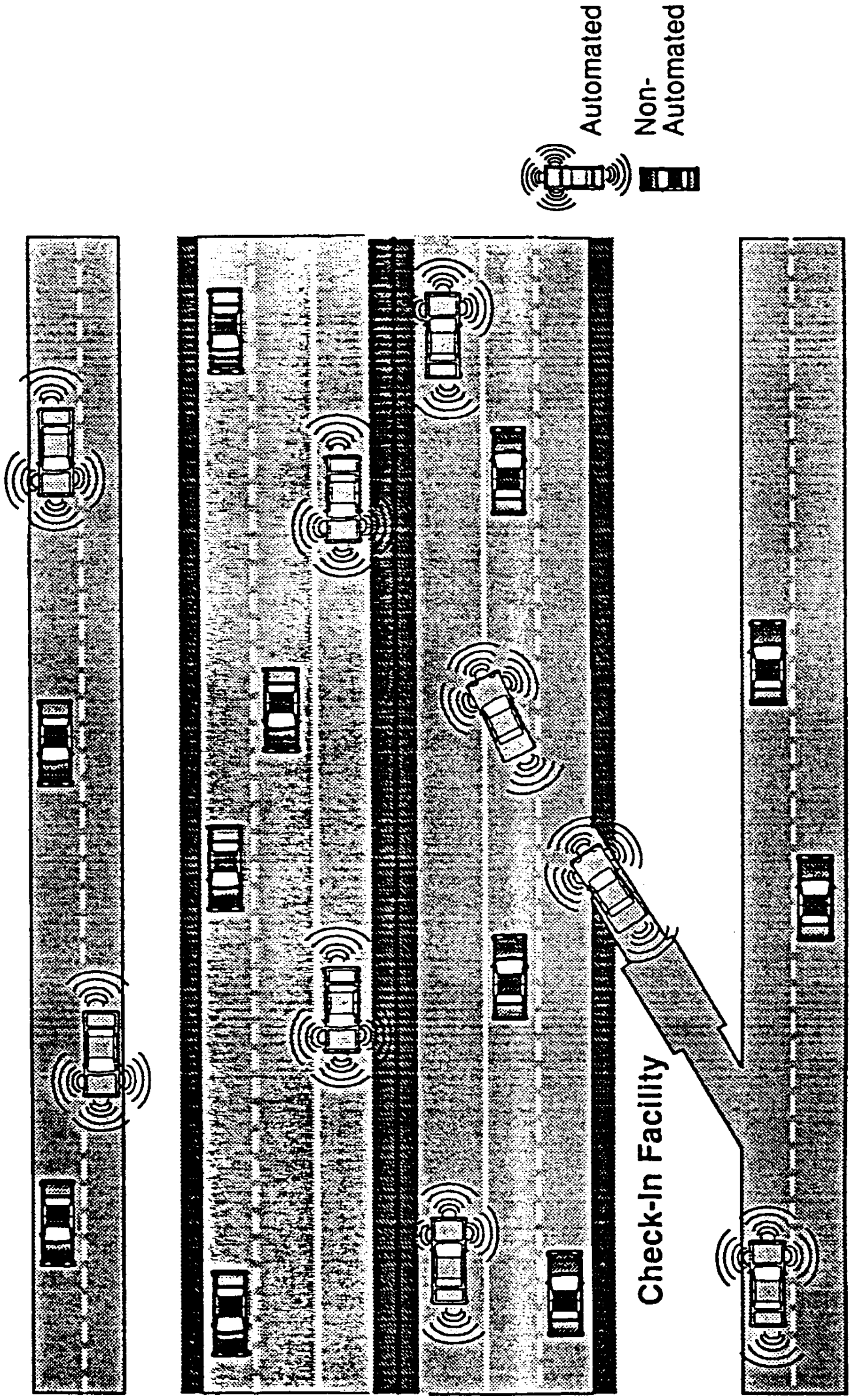


Figure 19. Check-in facility on a frontage road slip ramp.

driver expectation, critical to non-AHS system drivers in the mixed flow mode of operation. Figure 18 illustrates a concept of connecting entry/exit ramps to/from the left hand side of the AHS lane.

The level of need for separating the AHS traffic from the non-AHS traffic on the on or off-ramps will be dictated by the specific technology requirements of the check-in and check-out system. Some systems are envisioned to conduct this process "on the fly," minimizing the need to segregate AHS vehicles from the traffic stream. More sophisticated approaches may provide for rejection areas and queuing or staging areas for these processes.

Frontage roads pose an interesting possibility for locating ramp systems serving the AHS. Some freeway systems provide enough space between the frontage road and the freeway to locate check-in and check-out facilities, depending on spatial need. This alternative provides the opportunity to remove the impact of this operation from surface grid streets when queues or congestion develop during peak periods of operation. Figure 19 illustrates one conceptual application of how frontage roads could be utilized to provide entry/exit remote from the surface street system.

Construction of new access interchanges intended for the exclusive use of AHS vehicles has potential where adequate room is available or can be reasonably acquired. New interchange facilities of this type will requires bridge structures and drainage facilities to be coordinated with existing features.

Contrary to standard freeway design, AHS entry and exit points do not necessarily need to be located at the same interchange. Traffic distribution modeling should be used to determine the most effective location of entry and exit points, mitigating overloading the surface streets at congested locations. Thus, it is possible that entry may occur at one cross street, while exit may occur at another, with the area accessible by a good surface street roadway network. Access interchanges anticipated to not have critical traffic congestion problems can provide both entry and exit at the same interchange, if field conditions allow.

The spacing of entry and exit facilities is covered in detail in other Precursor System Analysis research Activity Areas. However, a basic consideration is that the location of entry and exit opportunities for AHS must consider the following:

- Traffic distribution on the AHS route and the opportunity for acceptable gaps in the traffic stream to accept new entries,

- Surface street traffic geometrics and congestion levels adequate to accept exiting vehicles reasonably, and

- Locating access to the AHS system at locations likely to attract users from major trip generators such as central business districts (CBD), regional attractions such as shopping malls, major residential and office concentrations, and major commuter traffic generators.

Locating exclusive AHS ramp access systems at surface streets which already have non-AHS ramp systems poses a special dilemma. Assuming the configuration was one that proposed ramps to/from the middle of the freeway, an additional traffic signal would be required at the surface street intersection. Thus, it is desirable to locate such facilities at other surface streets than those which already have ramp signals as a means of minimizing surface street disruption.

Operating Environment

Locations of ramps relative to the AHS lanes will be a function of available space for the technology employed for the check-in and check-out function and whether a barrier is to be used between the AHS and non-AHS lanes. Urban areas will be pressed for available space, making conversion of an existing interchange or HOV ramp system an obvious alternative.

Spacing between AHS interchanges is likely to be more of a concern in urban areas due to the typical trip interchange dynamics common to urban areas, suggesting more frequent spacing on entry/exit opportunities.

Rural applications are expected to generally have available space to accommodate most ramp system locations.

RSCs

The RSCs examined for this research assumed ramp configurations as shown in table 6 below. Figures 20, 21, and 22 illustrate how entry/exit configurations could be applied to some of the study RSCs.

Table 6. RSC ramp configurations.

RSC	Roadway Configuration	Ramp Flow		Location	
		AHS	Mixed	Right	Left
1	3 Lanes Each Direction Exclusive AHS Left Lane		X	X	
2A	3 Lanes Each Direction Exclusive AHS Left Lane		X	X	
2B	3 Lanes Each Direction Exclusive AHS Left Lane	X			X
2C	2 Non-AHS Lanes Each Direction Exclusive Reversible AHS Lane	X		X	
3	3 Lanes Each Direction Exclusive AHS Left Lane	X			X
4	2 Lanes Each Direction Mixed Flow in Left Lane		X	X	

As previously discussed, most of the above ramp configurations can be modified to fit specific field conditions and spatial availability combined with whether a barrier is employed or not. RSCs 2B, 2C and 3 could just as well have ramp systems connecting on the left hand side of the AHS lane, avoiding the cost of a flyover structure at each ramp.

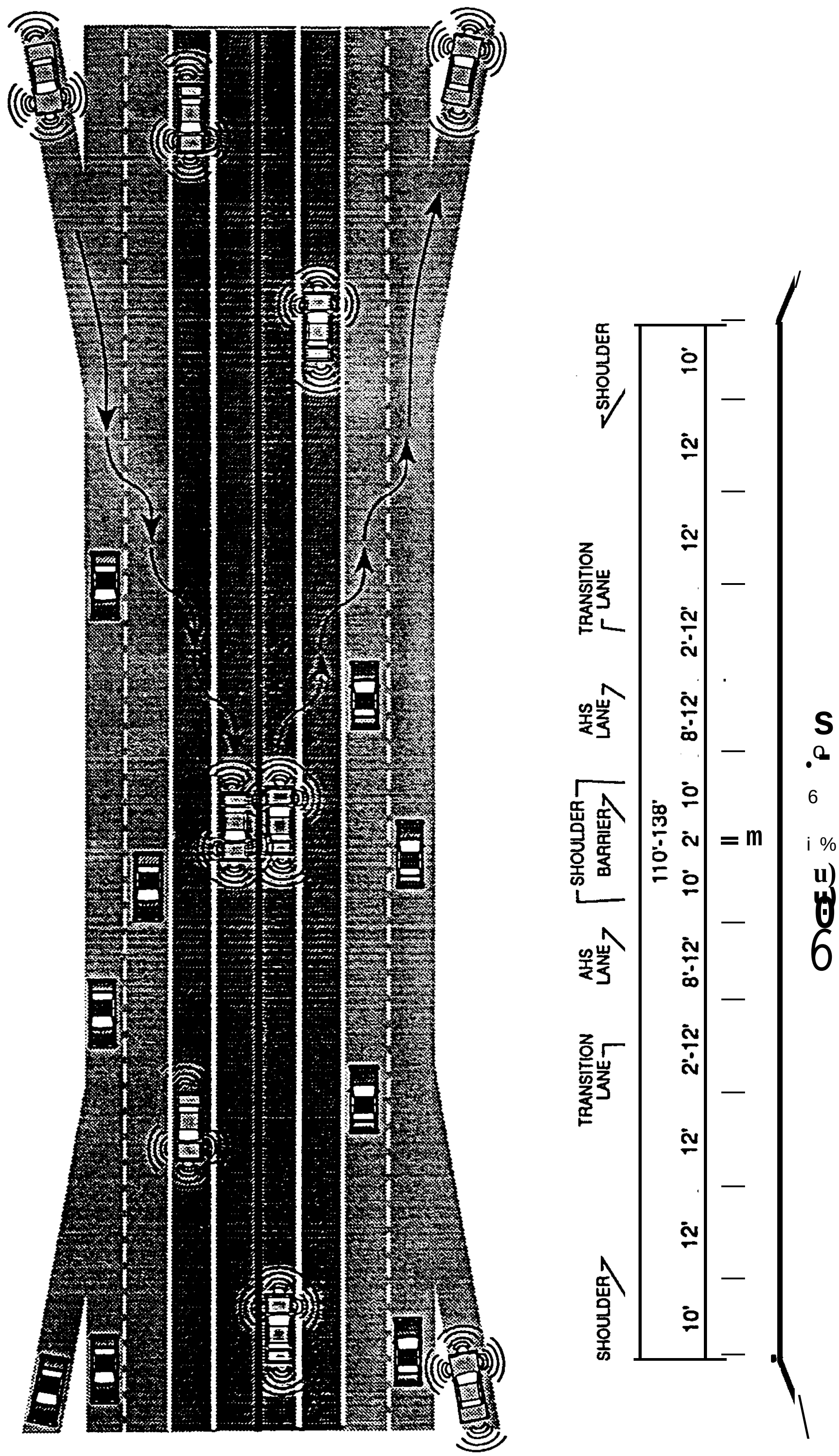


Figure 20. Access via transition lanes (RSC 1).

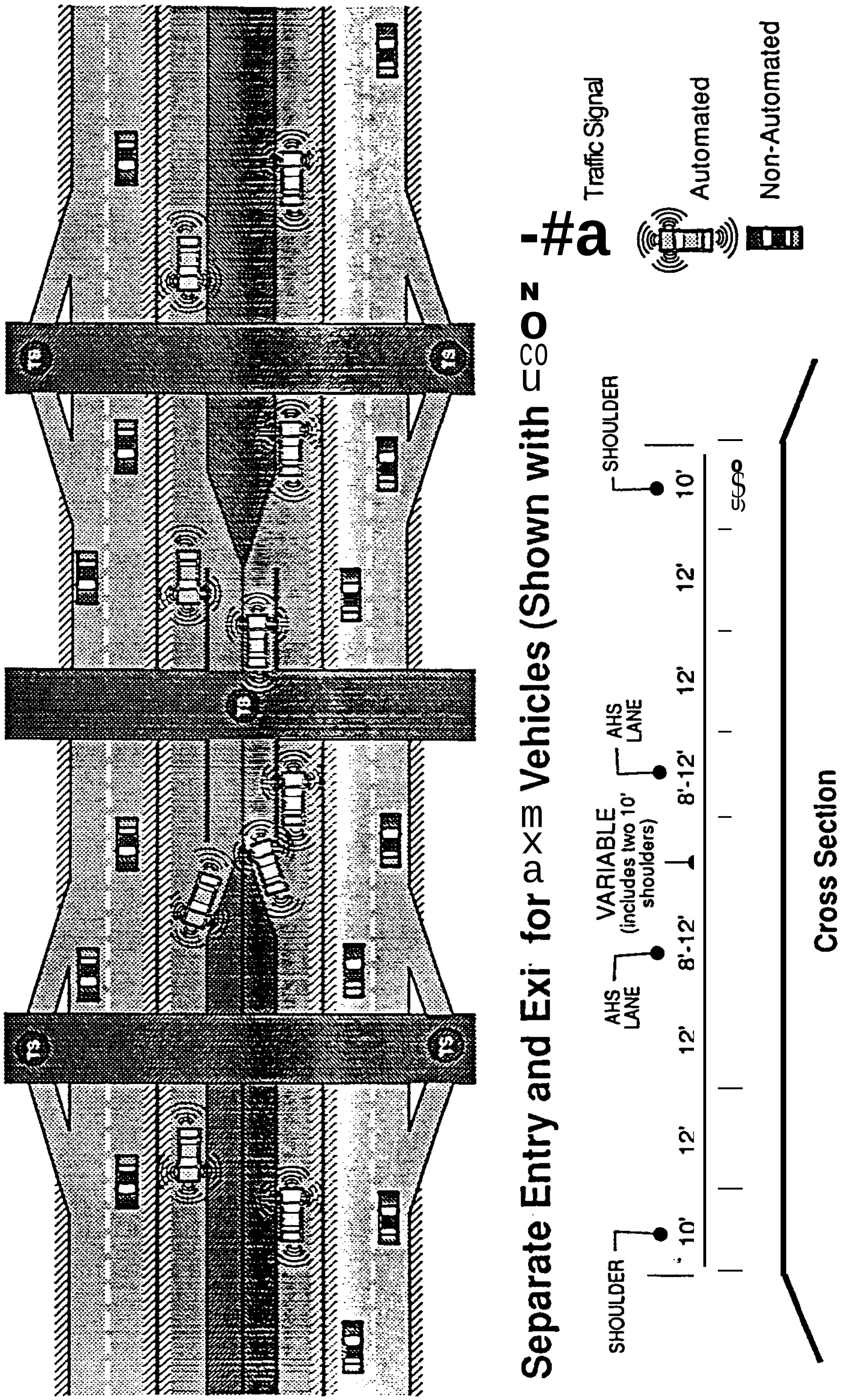


Figure 21. Separate entry/exit for AHS vehicles (shown with RSC 2A).

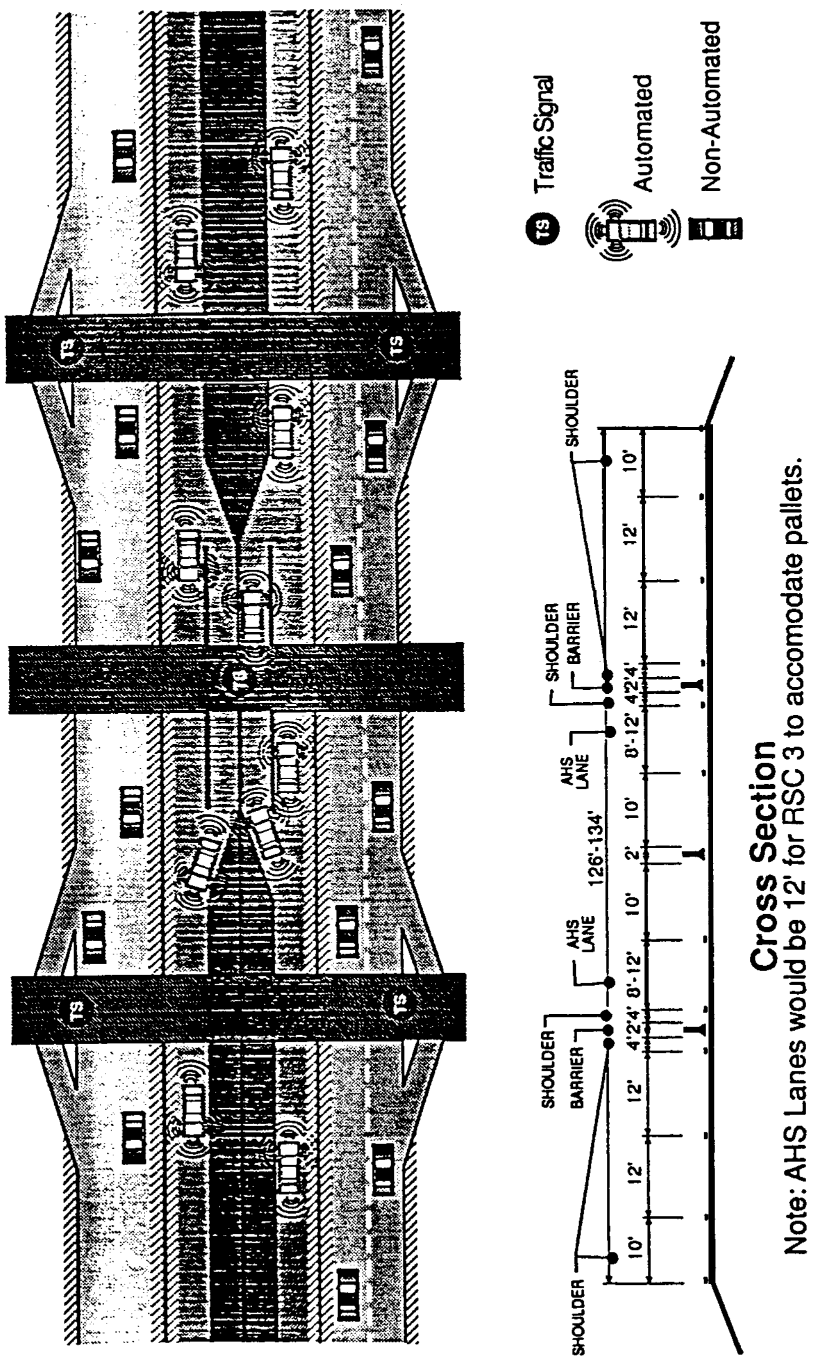


Figure 22. Exclusive entry/exit ramps directly to AHS lanes (RSCS 2B and 3).

Transition Lanes

In configurations which do not have AHS-exclusive ramps connected directly to exclusive AHS lanes, AHS vehicles are generally required to seek access to the AHS lane from the right hand side.

In configurations without barriers between AHS and non-AHS flows, the AHS vehicles must travel parallel to the AHS lane, and work their way over to the AHS area by using lane change opportunities while traveling with the non-AHS flow. Eventually, those vehicles position themselves in a lane parallel to the AHS lane and merge (transition) into the AHS lane. The lane to the immediate right of the AHS lane in this example is defined as the "transition lane." The transition lane runs parallel to and continuous along the entire length of an exclusive AHS lane.

In configurations which provide barriers with occasional gaps for merge and diverge maneuvers, transition lanes could be utilized on the non-AHS side of the barrier if adequate room is available. These transition lanes would not necessarily need to be provided for the entire length, but are most effective if continuous and limited to exclusive AHS use. Strict control on where merge and diverge maneuvers into/out of the AHS lanes must be employed to reduce the possibility of incidents. Figure 23 illustrates the application of a transition lane and an alternative to the continuous lane by widening out the space to allow adequate width for the design vehicle to make its maneuver, then transitioning down to a buffer space width.

The transition lane can serve the following purposes:

- Provide a space for final or full system checks and acceptance on the fly prior to physically entering the AHS-exclusive lane.
- Provide a space for initial or full check-out on the fly.
- Provide a space for the resolution of speed differentials between AHS and non-AHS flows.

Operational strategies may include providing mixed flow in the transition lane or restricting the transition lane to AHS vehicles.

Mixed Flow Transition Lane: Allowing mixed flow in a transition lane allows the freeway cross section to be limited to providing the AHS lanes in addition to the standard non-AHS lanes, since the transition function is accomplished in a lane which already exists. The disadvantage of this concept is that the difference in speeds between the two groups of traffic streams is anticipated to be significant, making the merging action potentially difficult if an AHS vehicle is required to wait for a safe gap in the AHS traffic stream. The same holds true for an AHS vehicle exiting the AHS lane. In cases where the transition lane flows are in a stop-and-go condition currently experienced by many major urban freeways in peak periods, the diverge maneuver of the AHS vehicles could have a significant negative effect on AHS operations as they seek gaps of attempt to come almost to a stop to force their way into the transition lane flow.

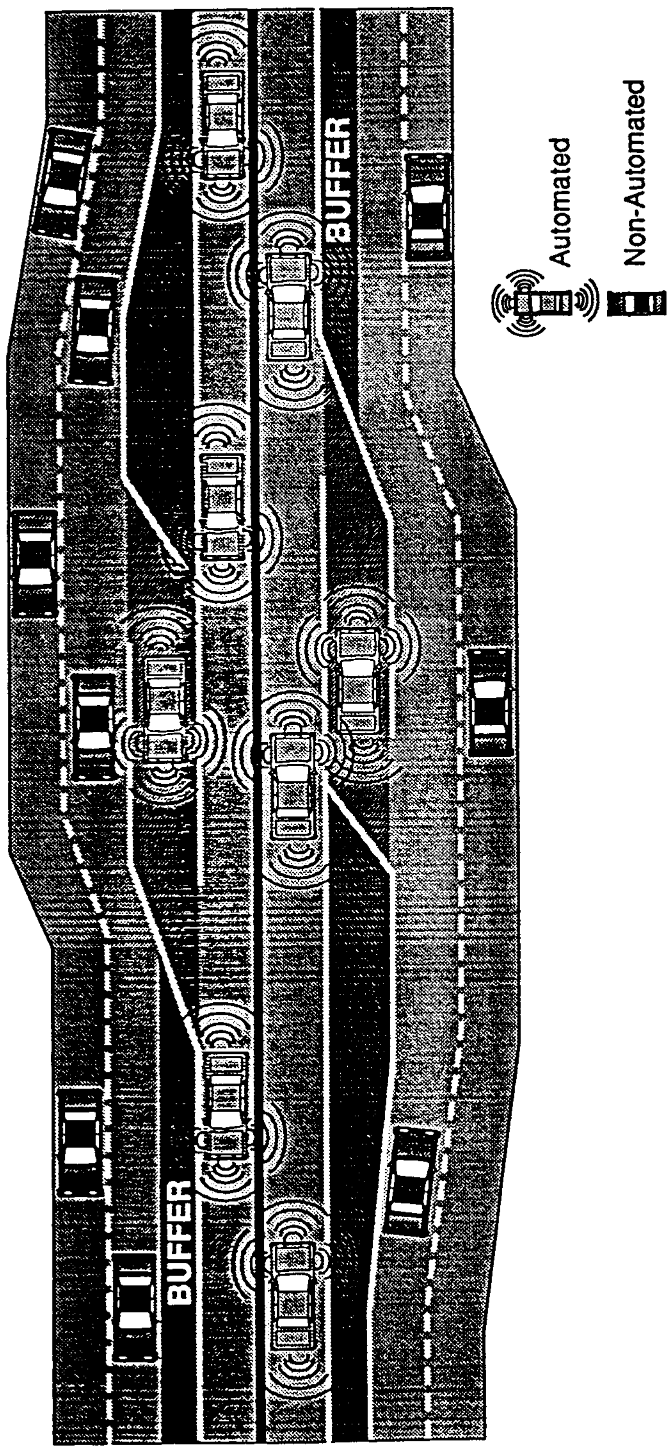


Figure 23. Access via transition lanes.

One possible mitigation to the diverge dilemma of providing a mixed flow transition lane is to provide a buffer space of adequate width to accommodate the AHS vehicle desiring to make the maneuver. The problem then becomes the frequency with which vehicles are attempting this maneuver in the buffer zone, and their relative proximity. Areas which are upstream from off-ramps or other reasons to diverge which may attract many vehicles from the AHS lane may provoke a line up of several vehicles in the buffer space attempting to force their way into the transition lane. However, if adequate width exists for such a wide buffer, consideration of an exclusive AHS transition lane may be more appropriate since merging and diverging from what appears to be a shoulder type of area has driver perception and safety issues associated with it.

Exclusive AHS Transition Lane: A potential solution to the merge and diverge speed differential issue is the provision of a transition lane limited to use exclusively by AHS vehicles. This concept requires adequate space to be available to provide the additional lane for the entire length in order to provide maximum effectiveness.

The primary advantage of the exclusive transition lane is that the merge and diverge dilemmas posed for the mixed transition lane are now physically removed from the AHS lane area, resulting in little or no impact to AHS lane flows. However, during peak periods where the non-AHS lanes are in a stop-and-go condition, this concept operates similar to the mixed transition lane concept which provided a wide buffer space because vehicles will be attempting to force their way into the non-AHS flows from a stopped or very slow speed condition.

<u>Operating Environment</u>

The desire to use the transition lane concept is strongest in an urban environment due to the need to resolve the speed differentials expected. However, the extra width required by the freeway cross section may be difficult to achieve in some areas where freeway expansion is difficult or impossible due to field conditions. Use of an adjacent non-exclusive lane for the transition operation may perform acceptable in non-peak periods, but is likely to break down considerably in peak periods.

In a special conference designed for participants in the Entry/Exit research tasks, participants agreed that a continuous transition lane that allowed access to or egress from the automated lanes anywhere along its length was not feasible. The results of this multi-team conference concluded that there would be dedicated areas for entry and exit separated by barriers, so that a vehicle could not travel from the entry portion to the exit portion, or vice versa. However, physical space required for the entry and exit transition could be continuous in areas with frequent entry and exit points.
Most rural environments could likely operate effectively by using the left-most non-AHS lane for the transition operation. Rural speeds tend to be consistently higher and gaps for the merge diverge maneuvers in both traffic streams tend to be available in sufficient frequency to support safe operation without the use of an exclusive transition lane.

RSCs

In the six RSCs examined in this research, the use of transition lanes is limited to those which do not provide barriers between the AHS and non-AHS flows, as shown in table 7.

Table 7. RSC transition lanes.

RSC	Roadway Configuration	Transition Lane	Barriers Used
1	3 Lanes Each Direction Exclusive AHS Left Lane	X	
2A	3 Lanes Each Direction Exclusive AHS Left Lane	X	
2B	3 Lanes Each Direction Exclusive AHS Left Lane		X
2C	2 Non-AHS Lanes Each Direction Exclusive Reversible AHS Lane		X
3	3 Lanes Each Direction Exclusive AHS Left Lane		X
4	2 Lanes Each Direction Mixed Flow in Left Lane	n/a	

In the RSCs for this research, the mixed transition lane concept was assumed. A buffer zone between the AHS lane and the non-AHS lanes is provided and could be used to resolve the merge and diverge dilemma.

The RSC 4 concept utilizes the leftmost travel lane of a two lane flow as a mixed AHS and non-AHS traffic lane. Thus, the concept of a transition lane is not applicable.

Frontage Roads

Frontage roads have traditionally been used as a means of access to the freeway, local roadways, businesses and other short distance trips along the freeway. In an AHS system, the frontage road system may assist in providing some of the facilities and traffic balancing associated with effective AHS operation.

Frontage roads could play the following roles in an AHS system:

- Provide alternative connections to AHS ramp systems, removing AHS traffic from an otherwise congested interchange area and promoting distribution of traffic away from a single point, and

- Provide check-in and check-out space between the frontage road and the freeway.

Figure 24 illustrates some of the potential applications and advantages frontage roads offer in AHS deployment.

Frontage roads may be one-way or two-way. Existing frontage road widths could be modified to provide exclusive AHS lanes or areas which could serve as access routes to the AHS facilities, with or without modification to the traffic flow directions currently in use. The advantage of this concept is that AHS traffic can be handled somewhere other than at an interchange located at a surface street. This advantage is magnified in areas where congestion is an issue.

One technique for dealing with this alternative access is in areas where adequate space exists between the freeway and the frontage road, processing facilities for AHS vehicles could be constructed without the impact of acquisition of additional right-of-way.

Frontage roads do not need to be continuous between interchanges. It is possible to construct a frontage road exclusively for the use of an AHS operation. The road could lead to an AHS processing facility, and not provide any other access or allow any mixed flow vehicles for any other purpose.

However, the frontage road concept requires space that may not be available in many areas. The most promising prospect of the use of frontage roads is the conversion of existing frontage roads for these purposes. Frontage roads which provide a higher level of local access to local roads or businesses may not be good candidates when contrasted with frontage roads which simply link interchanges, with no supplemental access connections.

The use of frontage roads along freeways to which major activity centers such as university campuses, major shopping malls or CBD areas abut offer the highest level of opportunity because of the major traffic attraction and the potential to gain the necessary right-of-way if widening is necessary to accommodate this feature.
The frontage road concept is most compatible with configurations which do not employ barriers between AHS and non-AHS lanes, but could be useful in exclusive AHS ramp configurations with appropriate bridge systems allowing AHS traffic connections between the facilities.

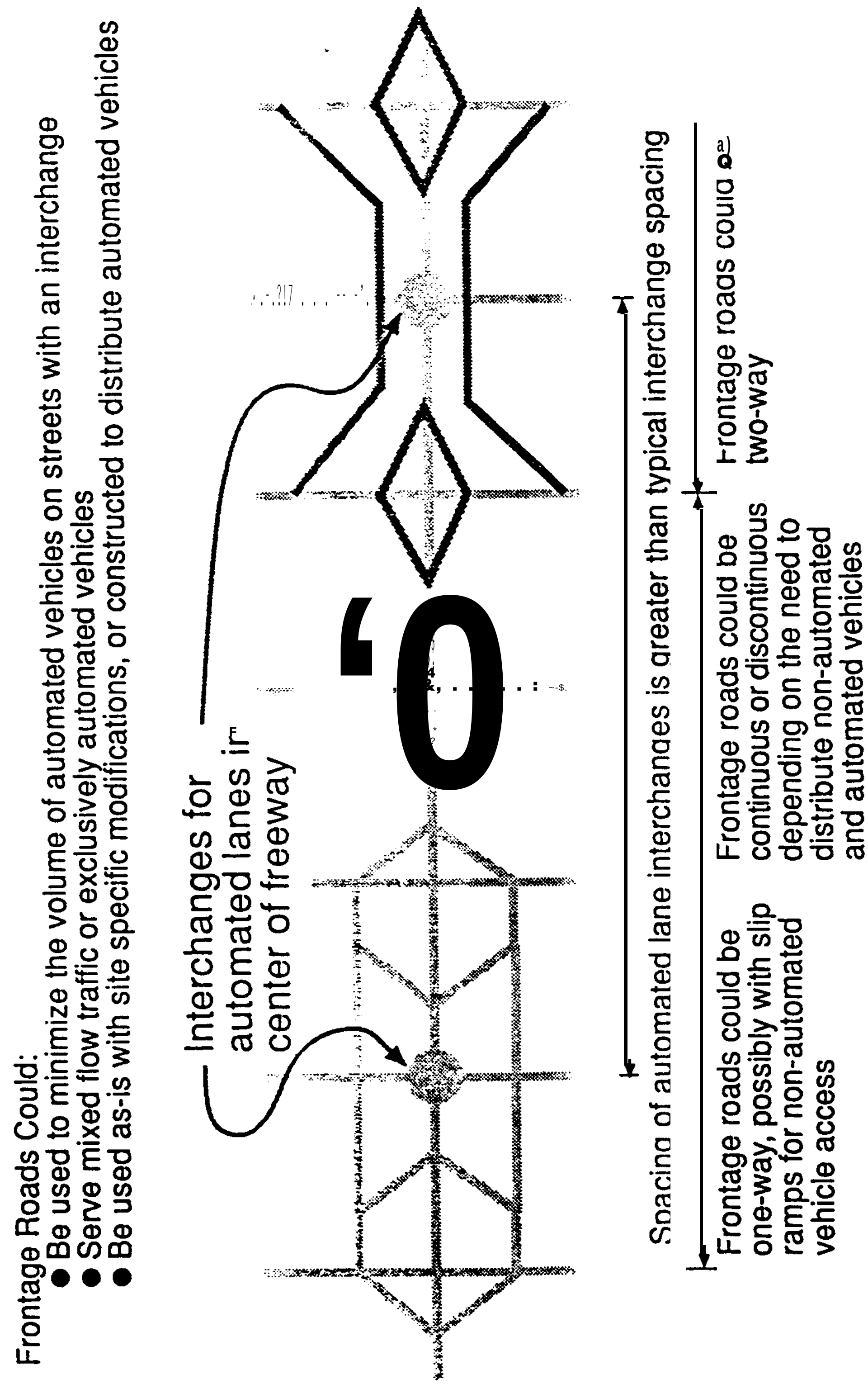


Figure 24. Application of frontage roads.

Operating Environment

Frontage roads are applicable in all operating environments. Their advantages in terms of traffic distribution are most useful in urban areas, where traffic congestion, when concentrated at single interchanges is important. However, unless the frontage roads exist in the urban area, acquisition of right-of-way for this purpose may be a major issue.

RSCs

None of the RSCs studied for this research implicitly contained the frontage road concept. However, under the appropriate field conditions, frontage roads could work well and provide certain spatial advantages to all of the RSCs. It is interesting to note that the frontage road concept may be particularly useful to the pallet concept described by RSC 3 as a means of providing space for the pallet operation and as a storage space.

The frontage road concept tends to have less impact on RSC 4, which contemplates mixed traffic flow in two lanes per direction, typical of current rural freeway standards, but could still serve as an available space for some functions.

INFRASTRUCTURE

For the AHS to provide the highest level of operational efficiency to its users, designers must adopt the philosophy that "down-time" for the overall system maintenance and repair operations should be significantly less than that currently experienced by typical modern freeway facilities. The system is envisioned as providing self-diagnosis to detect potential problems before they occur. Users of AHS will have an expectation of a higher quality and availability of service, similar to the expectations of users of other modern high-tech systems such as cable TV or cellular telephones.

This research examined the implications of the infrastructure elements at a high level, recognizing that the detailed elements of design will be highly dependent upon the system configuration employed and field conditions.

This section of the report offers discussion on the following topics:

- Instrumentation.
- Pavement Design.
- Drainage.
- Communications Plant.
- Traffic Control Devices.

Instrumentation

Instrumentation which may be considered by the designer of the freeway system providing AHS operations may include sophisticated sensors and telemetry elements to provide links between the vehicle and the roadway. Depending on the level of intelligence distribution between the vehicle and roadway, the level of devices to be provide by the roadway system is determined.

Instrumentation can include devices associated with:

- Active wire system embedded in the AHS lane for sensing lateral and longitudinal positioning of vehicles,

- Passive markers, such as magnetic nails, for lateral vehicle control,

- Roadside communications elements for carrying telemetry between the vehicle and the system control elements to control destination routing, headway, and speed,

- Sensor systems to evaluate weather and roadway surface conditions, and

- Check-in and check-out instrumentation.

In providing these types of instrumentation in the AHS system, the location of such devices is the primary concern for the freeway designer.

Some elements must be located in the roadway. In such cases, the design should be adequate to account for accessibility, if the element is one which may be subject to failure and repair (active electronic elements). The problem with elements in the roadway is that they pose a safety hazard and traffic flow disruption when under repair or maintenance, and should be minimized or avoided all together wherever possible.

Roadside elements can be located in barriers, on bridges, in the shoulder or outside of the paved area. The design criteria that should be used in developing the system should consider:

- Safe and reasonable location for maintenance personnel.

- Resistant to collisions.

- Resistant to vandalism or unauthorized tampering.

- Tolerant of the environment, including temperature, moisture and vibration.

When selecting the location for instrumentation, consideration must also be given to the type of materials, number of personnel, and equipment needed for repair and spatial accommodation. As an example, if lighting poles are to be located adjacent to the AHS lane, maintenance may require some form of bucket truck. The truck could operate from the AHS lane, with the system shut down, or it could operate from an adjacent shoulder with limited impact on AHS operations and exposure to potential danger. However, if space is provided outside of the traffic activity area, such as behind a barrier, the impact to ongoing operations and the safety of the personnel involved is minimized. The same should hold true when locating features such as electrical junction boxes, manholes and other accessible items.

Operating Environment

The urban environment is anticipated to be the most challenging for locating instrumentation elements. This is because space availability is at a premium in many urban freeway scenarios. In some cases, maintenance and repair access may only be allowed from within the AHS lane or AHS shoulder. This leads to consideration of how maintenance will be performed under AHS operating conditions. In some cases, certain maintenance and repair functions may require degradation or complete closure of AHS operations to accommodate the maintenance or repair activity. Some activities will be identified as a lower priority, allowing them to be addressed within a reasonable time frame, during planned periods of time in which AHS is inactive.

The rural operating environment is anticipated to offer the most generous availability of space for accommodation of instrumentation facilities. In this environment, it is likely that most, if not all, subsystem elements that can be located out of the actual AHS lane can and will be provided in safe locations, providing adequate access without negative impact to AHS operations.

RSCs

The level of equipment or elements required for instrumentation in the research RSCs is dependent upon the level of intelligence provided by the highway infrastructure. Table 8, below, summarizes the level of instrumentation anticipated by each of the subject RSCs. The descriptions portray three distinct levels of intelligence in terms of passive, average and smart, indicating successive levels of intensity.

Table 8. Instrumentation of RSCs.

RSC	Highway Intelligence	Vehicle Intelligence	Instrumentation Level
1	Smart	Average	High
2A	Average	Smart	Medium
2B	Average	Smart	Medium
2C	Average	Smart	Medium
3	Average	Smart	Medium
4	Passive	Smart	Minimal

As system concepts provide higher levels of intelligence and services provided by the highway infrastructure, higher levels of instrumentation can be expected. The most difficult implementation will be a smart highway, requiring a high level of instrumentation, in an urban area.

All RSCs in this research contemplate the communications between vehicles and roadside to be via the use of wireless technology connected to zone controllers. Thus, provisions for this equipment, although not necessarily needing to be located in intimate proximity to the AHS lanes, will be necessary in all RSCs.

Pavement Design

Durable and effective pavements for AHS lanes will have few distinctions from high-end pavements on existing freeways. Concrete traditionally is favored over asphaltic concrete because of its superior durability. However, cost and manufacturing considerations must be planned out in advance for concrete freeway lane construction away from urban areas.

Devices planned to be located in or under the AHS lane or shoulder must be thought out so that service access is allowed only to those elements that cannot otherwise be guaranteed workable for the life of the pavement. Strategies will be necessary to provide accessible elements in such a manner as to eliminate resulting pavement failure from water seepage into cracks around guide wire channels, magnetic nails, or other elements creating seams in the pavement.

Friction factors of AHS pavements must be maintained at or above existing freeway standards, including textured pavements which provide long lasting friction factors while minimizing vibration.

Some system configurations contemplate the lateral location of traffic to be fixed. Thus, if it is assumed that wheel tracks for all vehicles in an AHS lane are relatively fixed, or confined to a specific repeated location, it can be concluded that the weight distribution of each successive vehicle will repeat in the same spot on the pavement surface. Thus, to defeat load concentrations contributing to quicker pavement deterioration, alternatives such as a modified cross section to accommodate fixed load locations may be required.

An enhancement to existing pavement design which may ensure pavement durability would be to increase the depth of each pavement component. Providing full depth pavement immediately below the wheel path with reduced depths between and outside the wheel paths is not likely to be cost effective in terms of construction methodology, since the cost of forming distinct “tracks” probably offsets the savings in reduced depth elsewhere in the cross section.

An alternative would be to develop a system configuration with variable lateral vehicle positioning as a means of load distribution. Load distribution will become more of a concern as heavier vehicles are allowed to utilize the AHS system.

Operating Environment

The need for a durable and low maintenance pavement manifests itself equally in all operating environments. The distinction may be that special or complicated pavement or construction techniques may be more difficult in a remote rural area, where the support of services offered by the urban environment are more difficult. In most major roadway construction using concrete, batch plants can generally be located in the field at locations which help mitigate the effect of a remote operation.

RSCs

As in the operating environment, the RSCs generally tend to be equal in terms of pavement requirements, with the possible exception of RSC 3, which utilizes the pallet concept as a means or transporting vehicles from origin to destination.

Depending on pallet vehicle design and anticipated loadings, more extreme depths of pavement may be required. The need for higher friction factor surfaces when applications include pallets will require more detailed research to identify the necessity of gripping ability when considering how the pallet load is attached, and the tolerances of any such attachment mechanism and the safety considerations that are inherent in such a design.

Drainage

Removing water from the AHS lane will be a higher priority than that currently provided in typical freeways to support the higher speeds and safety expected of AHS.

Thus, designs should consider drainage facilities with higher water removal capacities than normal. The slightest flooding or accumulation of water on the AHS lane must be minimized to provide adequate friction between the tire and pavement surfaces.

Sensors may be designed and deployed which measure the surface characteristics of the pavement and advise the control system of conditions. The control system should then be able to account for reduced friction, and thus resultant braking ability degradation, by reducing speeds, if necessary.

Drainage of the pavement surface can be enhanced by providing a minimum of two per-cent cross slope and properly grooved pavement, avoiding designs which tend to create vibration for travel units. The direction of drainage will need to be determined on a case by case basis, recognizing that existing drainage facilities may or may not be utilized. In some cases, drainage will dictate hinge points in the overall freeway cross section to account for the change in surface runoff direction. In general, it is not desirable to run surface runoff from the non-AHS lanes across the AHS lanes to drain to an edge, as it adds to the runoff problem and exasperates the problem of keeping the AHS surface drained.

Separate drainage pipe systems may be necessary for AHS deployment if the original freeway drainage system cannot handle anticipated flows added by the AHS lane and shoulder areas, plus a safety factor of 20 percent. Slotted drains may be appropriate in the center of the AHS wheel tracks or along the edge of the AHS lane or shoulder as a means of enhancing quick removal of water. Catch basins may be utilized if oversized to accommodate rapid drainage of surface accumulation without pooling at the grate from heavy surges of water or blocking by debris.

Placement of drainage facilities such as drains, pipes and inlets should be minimized to reduce the need to interfere with AHS operations for maintenance and repair. It is most desirable to accommodate drainage outside of the AHS space by moving the surface runoff out of the AHS space as quickly and directly as possible.

Maintenance of drainage facilities to insure the quickest relief of drainage possible will be required, including occasional removal of debris from inlets and drop basins.

Operating Environment

Drainage capacity is a function of the amount of water being handled from a source. Generally, the source is described as an area producing runoff water from a source such as rain. Thus, if more lanes are drained by a single drainage system, the larger the area, the more water anticipated to an inlet. In urban areas where more lanes may utilize the same drainage system or inlets, adequate size of inlets is critical. Assuming adequate sized inlets are used, the distinction between urban and rural environments is null.

Thus, adequate accommodation of drainage is not environment specific, but based on adequate design, which should manifest itself equally in any environment.

RSCs

Drainage is distinct to field conditions of the specific freeway on which AHS s to be deployed. With the exception of physical barriers which may impede the path of water drainage, all RSCs are equal in drainage considerations.

The use of barriers between AHS and non-AHS lanes does not necessarily pose any difficult drainage problems, assuming the designer accounts for the channelizing effect the barrier provides. Techniques to address drainage flows along longitudinal barriers include slotted drains along the face side of a barrier, drop inlets along barriers, and occasional slots under barriers to allow drainage.

Communications Plant

In any concept of an AHS, some form of communications is necessary between the vehicle and the system. This communication may take the form of vehicle to roadside, vehicle to regional center, or vehicle to a more global destination such as a communications satellite.
Table 9 illustrates the variety of wireless communications technologies that may be applicable to AHS vehicle to roadside communications. A distinction is made between systems which may be owned and maintained by the AHS operating entity as opposed to those commercially available. Each has its own implications on maintenance responsibility and level of accommodation within the AHS design.

Table 9. Candidate wireless communications systems.

Owned Communications Systems	Commercial Wireless Systems
Area Radio Networks (ARN) Terrestrial Microwave Links Spread Spectrum Radio (SSR)	Cellular Radio Packet Radio Satellite

The level and need for infrastructure elements to support communications will be dictated by the specific technology used. For the purpose of this research, it is safe to assume that some sort of wireless receiver site is needed periodically along the freeway of deployment, and that these sites may be connected via land line or wireless technology. Candidate land line technologies applicable to AHS systems are summarized in table 10 below.

Table 10. Candidate land line communications systems.

Land Line Alternatives
• Twisted Pair Copper • Coaxial Cable • Fiber Optics • Leased Line Options —Local Exchange Carriers —Cable TV —Alternative Metropolitan Area Networks

The resultant infrastructure needs will include the possibility of providing conduits, junction boxes and manholes for the communications ground plant, and provision of adequate space for any receiver sites. Spatial needs may include a pad as large as 30 ft by 50 ft.

Operating Environment

Depending on the specific communications technology, construction in the urban environment may be less costly than the rural area, but more difficult if space is at a premium. Items as simple as conduits do not necessarily need to run directly adjacent to the AHS lanes, and may be accommodated on the right hand side of the freeway.

In rural areas, deployment is likely to be the same as the urban environment, but somewhat easier to accommodate due to the space availability. However, the long distances over which communications need to be accomplished may imply a mixture of communications media.

RSCs

All system concepts assume the provision of wireless communications between the vehicle and the roadside. The only distinction between the RSCs is the level of data exchanged, dependent on the intelligence levels of the subsystems, which tends to be more of a telemetry issue as opposed to a physical roadside implementation issue.

Traffic Control Devices

Traffic control devices may play a role in AHS deployment, as a means of clarifying right-of-way assignment, providing information and lane assignment. The role and application of traffic control devices in AHS systems is as follows:

Right-of-Way Assignment: Right-of-way assignment includes the clear conveying of information on who has the priority to make a movement, such as traffic signals utilized for ramp metering. In an AHS system, traffic signals may be used on ramps with mixed flows or multi-lane AHS exclusive ramps to indicate who's turn it is to enter the ramp. Traffic signals may also be utilized at check-in and check-out facilities to confirm acceptance or release from the facility, similar to applications currently in use at toll booths.

Providing Information: Signs are a typical example of devices provided to convey information. In an AHS application, signs may convey directional information, data on system operation/status/failure procedures, as well as a variety of standard traffic type information specific to the AHS.

Static sign displays, such as the green freeway signs indicating distances to ramps and destinations would be appropriate for conditions which do not change. For variable conditions, such as system status, special instructions to AHS drivers, or incident management can be deployed through the use of variable message signs.

Sign supports must be located safely yet allow maintenance access. Maintenance of variable message signs requires more space to access electrical and communications systems connected to the sign. Locations of signs may include mounting on bridge structures, overhead sign support structures, and roadside sign support structures.

Lane Assignment: The assignment of lanes, by indicating to drivers which lanes are available for AHS use can be accomplished by a combination of pavement markings and overhead electrical lane signals.

Lane assignment methods for AHS are more critical in application when the system concept is one in which no barriers are used to segregate AHS and non-AHS lanes. As a result, protection from intrusion by uninformed non-AHS drivers is a high priority. Thus, a high level of distinction between AHS and non-AHS space is critical.

Conveying lane assignment information to drivers may be done by:

Pavement Markings—Use of standard pavement marking colors to distinguish AHS lanes should utilize special symbology located in the AHS lane, identifying it as a special use lane. The diamond shape currently in use for HOV lanes may be an appropriate candidate as well as any innovative shapes proposed to and approved by the National Committee on Uniform Traffic Control Devices. Pavement markings longitudinal to the AHS lane should be wider than normal (8 to 18 in.) to signify to the driver the importance of the delineation between lanes. Pavement marking concepts should also reinforce the location and use of transition lanes, if applied in the system concept.

Signs—Static signs may be used to identify lane uses for conditions that never change. Such signs may be incorporated into the standard freeway signing scheme, and can be located as previously discussed along the roadside or overhead on bridge or other support structures.

Signals—Lanes which change use or direction during different times of day or in response to variable conditions related to flow proportioning or incident control may be identified through the use of overhead variable lane signals. Such indications are typically 18-in square and can be a single face with the ability to provide various shapes and colors with light emitting diode (LED) or fiber optic technology. Typical shapes and colors and their meanings include those shown in table 11.

Multiple AHS lane concepts may benefit from overhead lane signals by allowing different combinations of lanes to be open to AHS use as traffic demand requires. One concept may include three AHS lanes separated from non-AHS flows by a continuous barrier, with assignment of “open” lanes variable by direction, by time of day. Another alternative may be to provide two separate AHS lanes per direction, but utilize one for “local” trips and the other for “long distance” trips in an attempt to minimize the side friction caused by entry/exit maneuvers.

Experimentation is currently under way on additional lane use signal symbology, and should be considered for application in AHS designs if successful in ongoing field testing.

Table 11. Typical lane control signal symbols.

Symbol Shape	Symbol Color	Application
Down Arrow	Green	Lane available for use
“X”	Red	Lane closed
“X”	Yellow	Transition

Operating Environment

Application of traffic control devices is necessary to some level in all AHS systems. Complexity and level of sophistication and variety of devices will be dependent upon the complexity and physical composition of the system concept selected for deployment. Higher levels of traffic control devices will be necessary for systems which provide AHS lanes without barriers and exclusive ramp systems due to the potential of intrusion by non-AHS vehicles or driver confusion.

The urban environment is anticipated to require a higher level of traffic control devices for the above reasons and the higher level of driver frustration expected when non-AHS drivers observe better traffic flow performance in adjacent AHS lanes. This danger will manifest itself to the highest degree in congested urban areas where the AHS system is not located behind a continuous longitudinal barrier. Longitudinal barrier concepts which allow gaps for entry and exit of AHS vehicles from adjacent non-AHS lanes will offer limited opportunities for intrusion, and should be considered only as secure as the non-barrier system unless failsafe methods are devised to prohibit this intrusion.

The urban area is likely to involve more complex system concepts, such as non-barrier systems, barrier systems with exclusive ramps, and reversible lanes concepts. Each has its multitude of traffic control devices which will generally consist of a mixture of pavement markings, static signs and variable message signs.

Rural applications will require a lower level of traffic control devices, but again reflecting the requirements of the system concept. Thus, if the rural system concept involves the concept of mixed traffic flows, it will likely represent a static condition throughout the entire rural route, requiring only static controls such as signs.

Rural concepts that may involve the use of a separate exclusive AHS lane will require pavement markings similar to any such system deployed in the urban area, but the static nature of the rural system will allow signing as an effective complement to pavement markings.

RSCs

The complexity of the RSC will define the level of traffic control devices required. Table 12 summarizes the level of traffic control devices anticipated to be required for each of the research subject RSCs.

Table 12. Traffic control devices by RSC.

RSC	Roadway Configuration	Control Device						Control Level
		Marking	Static Signs	Variable Signs	Ramp Signals	Entry/Exit Signals	Lane Signals	
1	3 Lanes Each Direction Exclusive AHS Left Lane No Barrier	3	3	2	1	n/a	1	Med
2A	3 Lanes Each Direction Exclusive AHS Left Lane No Barrier	3	3	2	2	n/a	1	Med
2B	3 Lanes Each Direction Exclusive AHS Left Lane Barrier Separation	3	3	2	1	3	1	Med
2C	2 Non-AHS Lanes Each Direction Exclusive Reversible AHS Lane Barrier Separation	3	3	3	3	3	3	High
3	3 Lanes Each Direction Exclusive AHS Left Lane Barrier Separation (Pallets)	2	3	2	n/a	n/a	n/a	Low
4	2 Lanes Each Direction Mixed Flow in Left Lane No Barrier	3	3	2	2	n/a	1	Med

Key: 1 = Optional, 2 = Desirable, 3 = Required

CONSTRUCTION

Constructability

The notion of adding additional lanes to any freeway brings into play several issues related to converting available space to new useable space within an existing facility without drastic negative impacts on structures, drainage, and cross section. The issues presented are very similar to those that manifest themselves in HOV lane deployment, but with a few additional concerns due to the unique system concepts of AHS and its associated elements.

Items of construction may include:

- Dedicated lanes in the center of the freeway cross section.
- Shoulders and/or buffer spaces.
- Barriers.
- Transition lanes.
- Exclusive ramps or modifications to existing ramps.
- Entry/exit processing facilities.
- Communications plant.
- Instrumentation.
- Drainage systems.
- Control system elements.

Typical existing freeways may be considered as being a member of one of the following major classifications:

- Freeway with wide, unpaved median area.
- Freeway with narrow paved median utilizing a barrier to separate opposing traffic flows, with HOV lanes.
- Freeway with narrow paved median utilizing a barrier to separate opposing traffic flows, without HOV lanes.
- Freeway with HOV lanes in the center, utilizing barriers to separate opposing HOV flows and segregated from non-HOV lanes by barriers.

At first glance, the addition of AHS facilities appears to be a trivial exercise of simply widening and restriping and perhaps constructing barriers. However, upon closer examination of the subelements of freeway design when coupled with AHS considerations, the simple case becomes quite complex. Some significant factors contribute to the complexity of construction of an AHS:

- When a freeway is widened through a curve, the outside pavement edge on the curve may require to be raised to maintain a constant cross slope. As shown in figure 25, this change in elevation may result in longer side slopes in fill sections and in some cases require additional right-of-way or retaining walls. An alternative that may mitigate this effect is to utilize separate profiles for the two main directions of the freeway. This slope issue may also lead to inadequate clearance under bridge structures, requiring extensive revisions to profiles or structures.

- Existing freeways are not always centered within the right-of-way, causing potential problems with the amount of space available for containing the newly widened freeway section, as shown in figure 26. Mitigations may include realignment to the center of the right-of-way, acquisition of additional right-of-way or use of retaining walls.

- Freeways are commonly constructed with a center hinge point to create cross slopes for drainage. Depending on the location and capacity of the drainage system to accommodate the additional runoff anticipated from the new AHS space, hinge points may be developed at lane edges to direct runoff flows to more than one direction as a means for controlling water flows, as shown in figure 27.

- If an AHS system is proposed to be constructed to higher design speeds than the existing freeways in which they are to be contained, incompatibility between the superelevations, horizontal and vertical curvature will be major issues. For example, an existing horizontal curve on a freeway will have a tighter curvature than that of a higher speed curve, but are desired to coexist side by side. A mitigation of the issue may be to provide AHS with higher friction factor pavement or design AHS to design speeds compatible with adjacent facilities.

- Existing structures provide clearance over the existing roadways so that vehicles do not strike the bridge structure. In the case of a bridge located on a horizontal curve, the pavement below is superelevated so that the outside of the curve is higher than the inside of the curve. If minimum clearance heights are currently present, the addition of new lanes matching the surface slope currently in place may cause inadequate vertical clearance between the bottom of the existing bridge structure and the new AHS lane. Mitigations may include a separate profile for the AHS lane or modification to the bridge structure.

- Existing structures may have supports in the center of the freeway in locations unavoidable by the AHS construction. In some cases, although the actual lanes and shoulders of the AHS may not be in direct conflict, the bridge support may be located in close proximity to the left shoulder edge. In such a case, a reasonable mitigation may be provide barrier systems to protect the support. In cases where

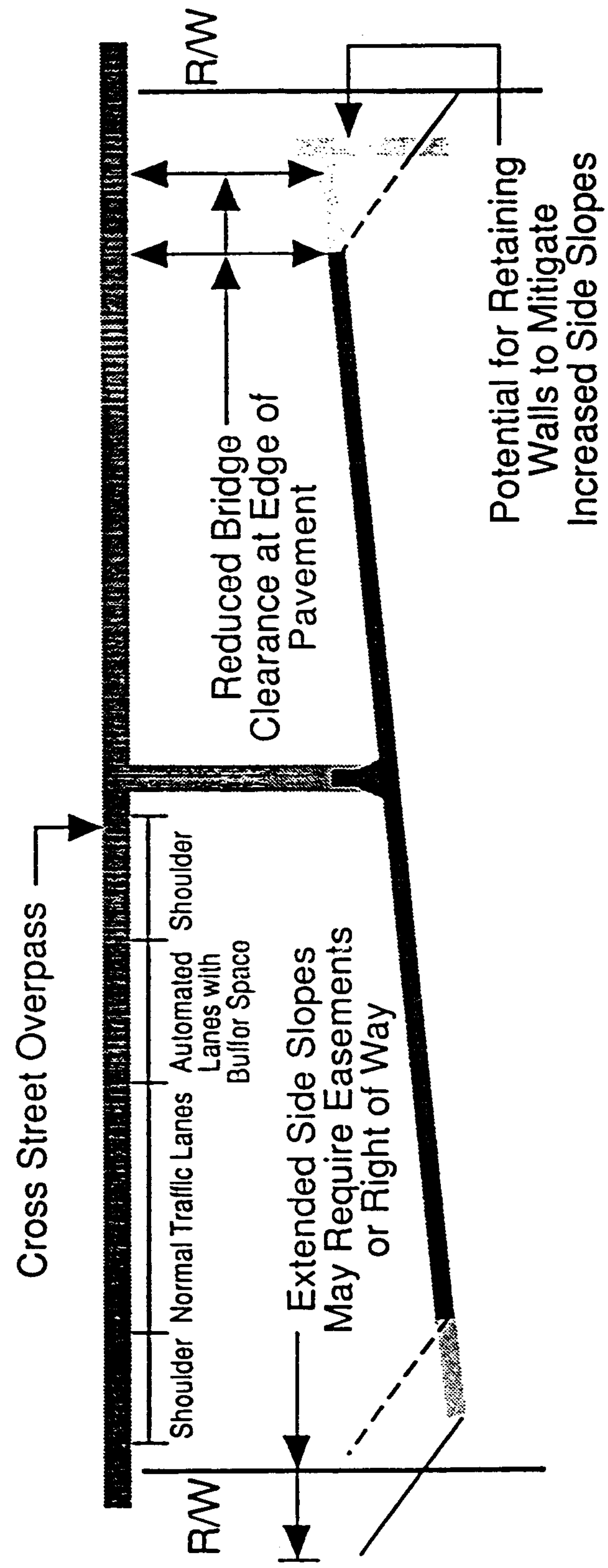


Figure 25. Impacts of widening on a curve to provide inside AHS lanes.

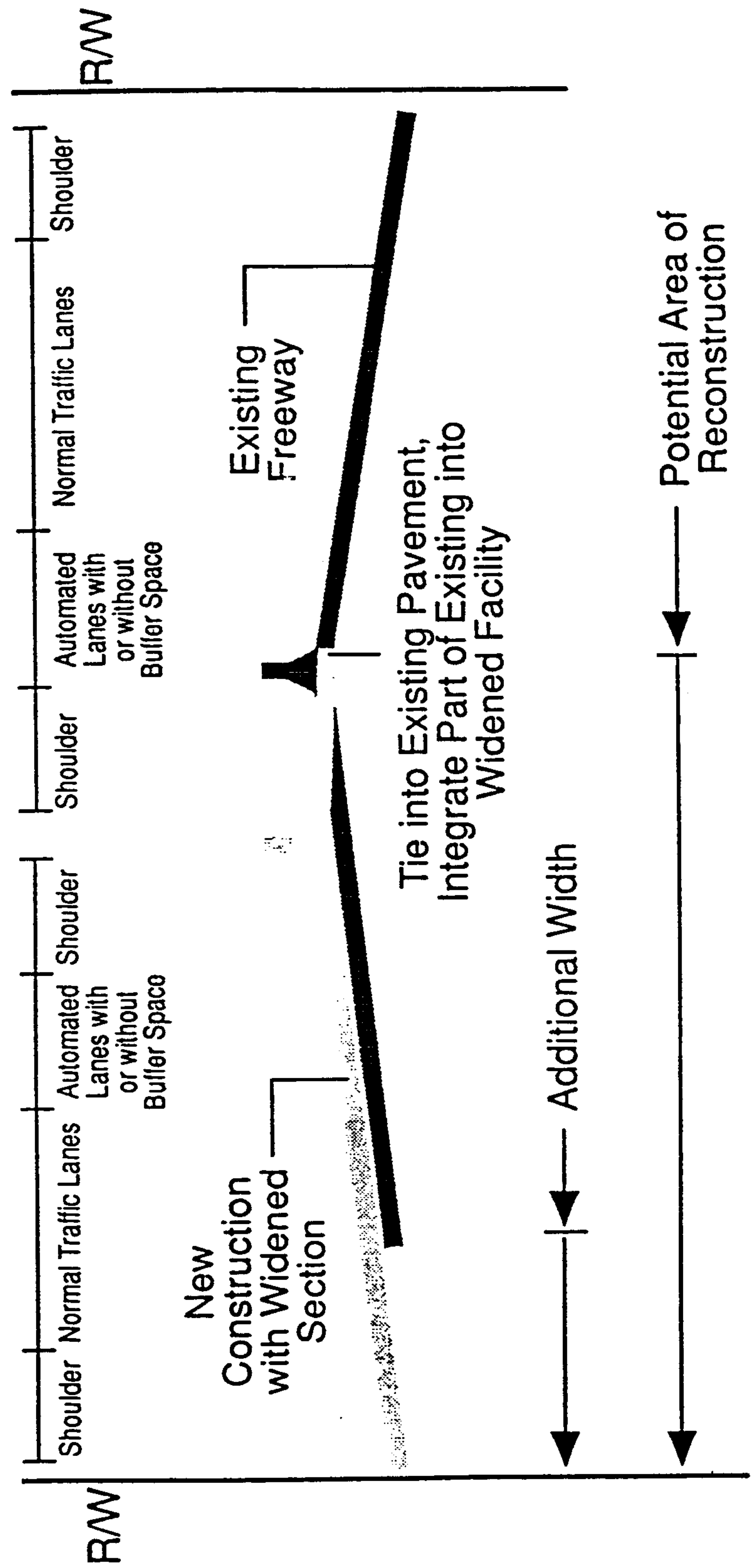


Figure 26. Impact of widening a freeway not centered in ROW to accommodate AHS lanes.

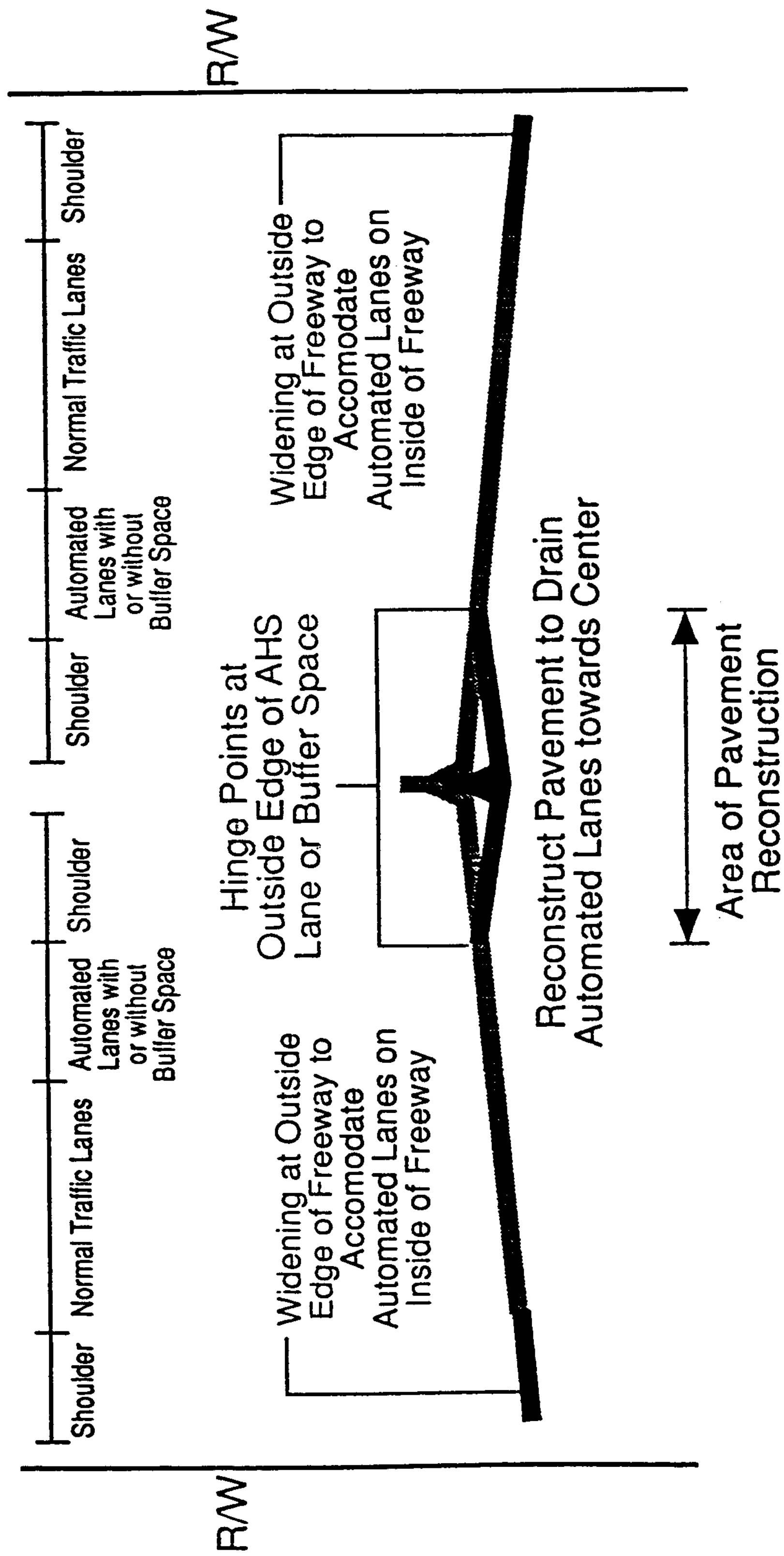


Figure 27. Impact of introducing inside AHS lanes with center drainage.

the support will definitely be an obstruction to the AHS lane or shoulder, extensive reconstruction of the bridge may be required. Alternative treatments may include grade separation as a means of avoiding obstructions.

- Existing bridges along the lanes adjacent to the new AHS may not be wide enough to accommodate additional travel lanes and shoulders. A mitigation to this issue includes modifications to bridges to either reconstruct to an appropriate width or to attach a cantilever bridge section to support the new lane space.

AHS Costs

The nature of construction associated with implementing dedicated automated lanes is very similar to implementing HOV lanes on a freeway, with the possible exception of additional entry/exit facilities, and constructing communications and instrumentation elements. As was discussed under “Constructability” issues and as determined by the site-specific applications of various RSC's, the physical limits of construction can be more extensive than simply adding pavement towards the inside or at the outside edges of the freeway. In fact, the degree of reconstruction required to add dedicated lanes can be so extensive that it can involve nearly complete reconstruction of a freeway.

An example of the isolated costs of an HOV system is the 47 miles of HOV lanes constructed in Houston on the Gulf, Katy, North and Northwest freeways between 1984 and 1988. These were constructed at an average cost of $4.7 million per mile (in construction year dollars). Typically the HOV lane was a 20-ft wide reversible roadway, including shoulders, with barriers separating it from other traffic. The cost of these HOV facilities was generally minimized by constructing the HOV lane with minimal right of way acquisition, and by constructing the lane concurrent with other freeway renovation.

These costs are corroborated somewhat by estimating the cost of some key construction elements for the conceptual plan developed for the I-394 test case, in which RSC-2C was overlaid onto that freeway in the western suburbs of Minneapolis. These estimates were based on the following assumptions:

- All overpasses in the segment of I-394 under consideration were replaced in kind, since the centered AHS lane conflicts with center bridge piers. This type of replacement is not uncommon on HOV projects, due to similar reversible lane scenarios, as well as replacement needed to correct inadequate or maintain adequate vertical clearances.

- The pavement in the inside shoulder areas was assumed to be removed as part of the reconstruction to implement the AHS lane.

The following list of construction items (table 13) is not complete. It does not account for such items as drainage modifications or items related to changes in vertical conditions, such as earth work. Finally, it is based on one possible approach to implementing an AHS system using a single method of applying one of six possible RSCs resulting in a cost per mile of $3.6 million.

Table 13. Prototype AHS costs.

Item	Quantity	Unit Cost	Total Cost
Removal of Barrier	10,950 L. Ft.	$ 3.00/L. Ft.	$ 32,850
New Barrier	21,800 L. Ft.	$ 40.00/L. Ft.	872,000
Removal of Bridge	80,350 Sq. Ft.	$ 3.00/Sq. Ft.	241,050
New Bridge	80,350 Sq. Ft.	$ 80.00/Sq. Ft.	6,428,000
New Rail Bridge	2,850 Sq. Ft.	$ 150.00/Sq. Ft.	427,500
Remove Asphalt	25,500 Sq. Yd.	$ 2.00/Sq. Yd.	51,000
New Pavement	16,850 Tons	$ 30.00/Ton	504,900
		Total:	**$ 8,557,300**

In reviewing cost estimates from other research efforts, it was determined that a vast range of cost was identified by the various researchers. The range of costs for implementation of an exclusive lane AHS facility on an existing freeway was from $3.6 million to $20 million per mile.

Conversion Strategies Without Extreme Construction

In the context of this section of the report, conversion is intended to describe the condition in which existing HOV or other space is converted to AHS use without extensive construction. The advantage of conversion of existing space is that it is anticipated to be less costly by avoiding extensive physical reconstruction and would be less time consuming.

Opportunities present themselves in freeway sections which have existing HOV lanes. Some freeways also provide wide paved surfaces intended for future HOV facilities. Both are an excellent candidate for AHS conversion because physical space exists, the drainage system is likely already sized to accommodate the runoff, and bridge structures are already wide enough to be compatible with the new lanes and sufficient clearance exists at bridges.

Many modern HOV systems, including one of the sites reviewed in the Specific Site Analyses section of this report, provide completely separate lanes and ramps for an existing HOV facility which may be readily converted to AHS use. In such cases, this condition only provides the physical roadway element. Communications, instrumentation and control systems must still be accommodated and will require construction activity.

Connectivity

A basic requirement in establishing connections between freeways with AHS should be that the AHS lanes be continuous throughout the interchanges connecting such freeways, without the need to change lanes via the non-AHS lanes or exit the first freeway to enter the second freeway. The advantage would be that a continuous design eliminates unnecessary lane changes, slowing and merging maneuvers outside of the control of the high safety factor environment of AHS.

This concept makes existing freeways with HOV systems providing this continuity especially attractive as a conversion strategy.

Termination of AHS Facilities

AHS lanes must have a beginning and an end. Two strategies may be utilized to terminate AHS lanes:

- AHS lanes may initiate their presence by widening the freeway somewhere between interchanges. This technique involves providing sufficient tapers, advance signing and can be used only in design concepts which do not separate AHS and non-AHS flows with longitudinal barriers without gaps. Ending AHS lanes may be accommodated in similar fashion by transitioning the width with adequate tapers and channelizing traffic back into the non-AHS lanes.

- Begin and end the AHS lanes at an interchange, when the system configuration provides separate AHS lanes separated from non-AHS flows by barriers, and exclusive AHS ramp systems are connected directly to AHS lanes.

Both strategies are illustrated in figure 28.

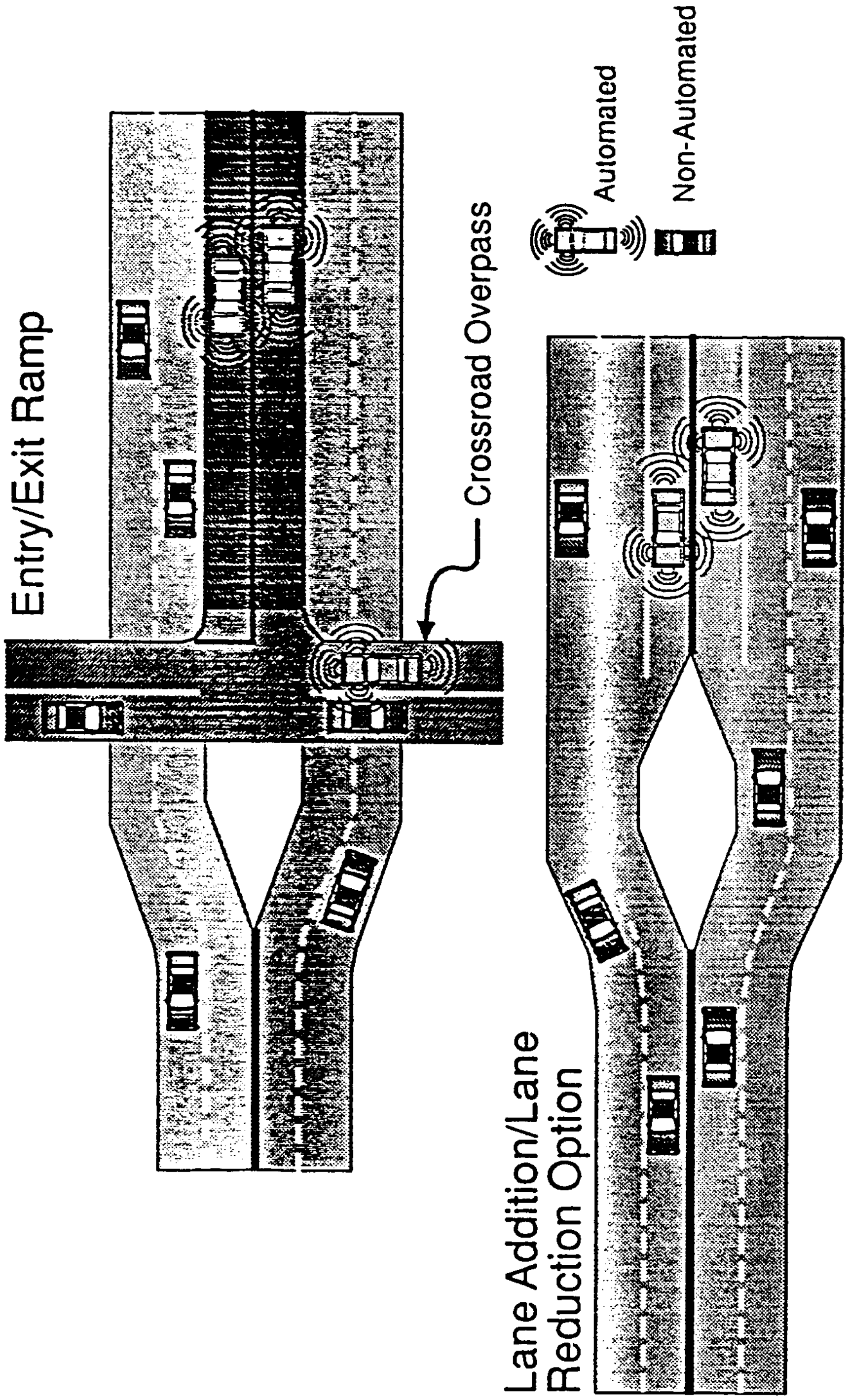


Figure 28. Terminus options for automated lanes.

SPECIFIC SITE ANALYSES

Four existing sections of freeway were evaluated to determine the specific impacts of implementing automated lanes within these corridors, based on the research presented in the previous sections of this report. The intent is to determine the reality of AHS application when tested against real-life scenarios for the four sample freeways. The sites were selected to represent four distinct physical environments—urban, rural, fringe or urban area, and a small population center located in a rural environment. A description of the four sites follows, and graphic illustrations of the specific sites and the applied AHS configurations appear in appendix C.

Urban Environment: I-10, Phoenix, Arizona

This site was selected to represent urban freeway conditions. The eight-lane section under consideration extends from just west of Seventh Avenue to the interchange with the Squaw Peak Freeway and the Red Mountain Freeway (SR 202). Key features include urban interchanges at 7th Avenue and 7th Street, a half-diamond interchange at 16th Street, and an overpass at Central Avenue. The most unique features of this section of freeway are the tunnel between 3rd Avenue and 3rd Street where the entire freeway cross section is contained underground, and the buffer-separated HOV lanes on the inside of I-10. The HOV lanes have HOV-only ramps at 3rd Street and 5th Avenue/3rd Avenue (a one-way couplet), and continue along I-10 south of the Squaw Peak interchange and to the east along Highway 202 via exclusive ramp structures at a stacked interchange, allowing free flowing HOV conditions in those directions.

Rural Environment: I-10 between Tucson and Phoenix, Arizona

This site represents a rural condition. Typically the roadway has two, 12-ft lanes in each direction with 10-ft outside shoulders and 4-ft inside shoulders. Interchanges are infrequent, with spacing ranging from 10 to 28 miles and are typically diamond configurations. The design of this freeway section is typical of rural freeways found throughout the country.

Fringe Environment: I-394, west suburban Minneapolis, Minnesota

I-394 between Winnetka Avenue and Trunk Highway 100 is located in a transition or “fringe” area in terms of land use, and the context in which the term “fringe area” is used in this research effort. The freeway runs from the CBD of Minneapolis through the western suburbs, becoming a non-access controlled US highway continuing into rural areas. There are six lanes west of TH 100, with the inside lane in each direction being an HOV lane immediately adjacent to general traffic. Near TH 100, the HOV lanes transition into a reversible, barrier-separated facility.

Small Population Center in a Rural Environment:
I-35, through New Braunfels, Texas

New Braunfels is located about 30 miles northeast of San Antonio, with a population of about 30,000. This location was selected as representing a freeway through a small population center in a rural environment. This freeway changes character from a rural 4-lane section north and south of town, to three lanes in each direction through the city. Typically, access to the freeway is via a series of diamond interchanges connecting to two-way frontage roads on each side of the freeway. Since the frontage roads are two-way, the slip ramps near the crossroads intersect the frontage roads at right angles to allow left and right turns onto and from the ramps.

Each specific site freeway section was evaluated against at least one candidate RSC to assess the consequences and options of implementing AHS. The results of these evaluations are summarized as follows.

<u>Urban Environment: I-10, Phoenix, Arizona</u>

This site was evaluated using RSC 2C—barrier separated automated lanes—with the general concept being that the HOV lanes and ramps would be converted to AHS lanes and that the HOV lanes would not be replaced. Key design objectives included meeting AASHTO standards for non-automated lanes and shoulders, and meeting the minimum standards set forth here for automated lane widths and shoulder requirements.

A layout of the corridor was prepared using these design assumptions, and is contained in the Appendix of this report. The key findings of this exercise are as follows.

- By doing any necessary widening into the median, the automated lanes and associated shoulders and barriers fit within the existing roadway footprint such that no widening of the freeway would be required, if 4-ft (sub-standard) inside freeway shoulder widths were utilized.

- The available width for the automated lanes and for the shoulders adjacent to these varied depending on the median width. The automated lanes varied in width from 8-ft (the proposed minimum) to 12-ft (the proposed maximum). The shoulders were in all cases at least 4-ft on one side and 10-ft on the other (both proposed minimums). In some cases, 10-ft shoulders are shown on both sides where the existing median width provided precisely enough space for those shoulders plus barriers and 12-ft automated lanes.

- The most constrained location for widening was in the tunnel. All available space was used to provide 8-ft automated lanes with 4- and 10-ft adjacent shoulders, a barrier between the automated lane and the normal traffic lanes, a 4-ft inside freeway shoulder and maintaining the existing freeway lanes and outside shoulders. So it would be possible to provide all features with minimum acceptable widths in the tunnel except for the inside shoulder.

- Outside the tunnel, the most common compromise was again the use of the 4-ft inside shoulder to prevent the widening of the freeway to the outside. The trade-offs involved in providing a larger inside shoulder could include the following impacts:

  — New retaining walls in cut areas to avoid right-of-way acquisition
  — Replacement of structures due to conflicts with piers or abutments, or reduced vertical clearance at edge of pavement
  — Realignment of ramps near the freeway lanes
  — Modifications to drainage systems
  — Impacts to existing landscaping
  — Construction of noise walls due to reduced distance between the edge of roadway and sensitive receptors.

With the exception of RSC 4 (mixed flow), all RSCs would require some amount of space, and therefore some widening, within the freeway right-of-way to be dedicated to automated lanes plus associated barriers and shoulders. (RSC 4 requires no part of an existing facility to be dedicated solely to automated vehicles, since the automated and non-automated vehicles would operate in a mixed-flow condition.) These spacial requirements vary from as little as 16-ft of dedicated AHS space with RSC 2A (exclusive AHS lane on the left side, mixed access condition) to a maximum of 56-ft with RSC 2B (exclusive barrier-separated AHS lanes) and RSC 3 (exclusive barrier-separated AHS lanes utilizing pallets). Thus, the above list of widening impacts generalizes considerations associated with any widening required to accommodate an AHS system.

<u>Rural Environment: I-10 between Tucson and Phoenix, Arizona</u>
<u>Fringe Environment: I-394, West Suburban Minneapolis, Minnesota</u>
<u>Small Population Center in a Rural Environment: I-35, through New Braunfels, Texas</u>

Each RSC would have a similar set of potential impacts for a situation that involves widening (RSC's 1, 2A, 2B, 2C, and 3). Therefore, a key conclusion of this exercise is that implementation of an AHS system into an existing freeway using dedicated lanes for automated vehicles would be similar in physical scale and impacts—and thus similar in cost—to the implementation into an existing freeway of other types of facilities using dedicated lanes, such as HOV lanes or busways. Implementation of an AHS system with mixed flows would be a distinctly different, and less extensive construction undertaking.

Some observations from the site analyses are:

- *I-10 between Phoenix and Tucson*—This site has an identical cross section to RSC 4. Therefore, implementation of this RSC in this setting would involve relatively minimal construction, primarily associated with communications and instrumentation.

- *I-394 in Minneapolis*—This site was tested with RSC 2C—automated vehicles operating in a single, barrier-separated reversible lane in the center of the freeway. The primary unique impact of this situation is that the automated lane is that it conflicts with existing center piers. Therefore, it would need to be constructed offset from the center line of the freeway, or centered within the freeway with any overpasses being reconstructed such that the center piers align with one or both barriers along the automated lanes.

- *I-35 in New Braunfels, Texas*—This site could readily be retrofitted to accommodate RSC 4, and widening could be implemented into the expansive median for any of the other RSCs. If any widening to the outside was required for special circumstances, the key impact would be revisions to ramp alignments. This would present a challenge in that the radii at the end of many of the ramps near the frontage roads is typically minimal. Any widening of the freeway would potentially exaggerate this situation by reducing the distance between the frontage road and the freeway available for the ramps.

The general conclusion of this exercise is that deployment of AHS is highly sensitive on a site-by-site basis. Thus, if a nationwide system concept is to be selected, care must be taken to evaluate the compatibility of the concept design on the roadways on which it is intended to be applied. Potential mitigations of some of the issues discovered above may be to convert entire roadways to AHS-only operation or to select multiple configurations, taking care to insure compatibility between control systems and strategies on a national level.

CONCLUSIONS

The following summarizes the primary conclusions of this research relative to deployment of AHS:

Spatial Needs

Lane Locations:

- Exclusive AHS lanes should be located on the inside (to the left as viewed by the driver) of a freeway.
- Mixed flow configurations can use any existing lanes.
- Conversion of existing lanes is possible, but should be thoroughly studied on a site specific basis.
- Wide, unpaved medians are an opportunity for constructing additional lanes.
- Grade separated facilities may be considered where freeways cannot be physically widened.

Lane Widths:

- Exclusive AHS lanes can be less wide than standard lanes (8- to 12-ft) based on the design vehicle.
- Mixed flow AHS systems should have lane widths compatible with the mixed fleet of vehicles served.

Shoulders:

- Full-width shoulders should be provided on the left side of an exclusive AHS lane.
- Shoulders should be provided on both sides of exclusive AHS lanes which are separated from non-AHS lanes by a concrete barrier or operating in a reversible lane configuration. Only one shoulder would need to be full-width.
- In a mixed flow strategy, typical AASHTO design requirements would apply, with full-width left and right shoulders appropriate for freeways with three or more lanes.

Barriers:

- Perceived barriers are only slightly more effective than striping as a means of insuring traffic separation, and will not prevent accidental or intentional intrusion into AHS lanes.

- Positive barriers offer the highest degree of safety and access control, and are desired to separate AHS and non-AHS traffic.

- Positive barriers should be used when AHS lanes have exclusive ramp systems that do not require AHS traffic to mix with the non-AHS traffic to reach the ramps.

- Positive barriers may be used in configurations where AHS lanes are required to use mixed flow ramp systems, but careful attention must be paid to the design to mitigate safety and traffic flow issues. Speed differential between AHS and non-AHS lanes at barrier gaps is a major issue in locating gaps.

Right-of-Way:

- Some existing freeway rights-of-way cannot be widened due to existing development, social, and political concerns.

- Freeways with limited space and no possibility of additional right-of-way for widening will require examination of alternative treatments, such as grade separation, limited AHS operation, lane conversion, or adjustment of how the existing cross section is used.

- Right-of-way is most expensive in an urban core, decreasing in cost as one moves to the fringe and then rural environments.

- Right-of-way width may range from 325- to 525-ft, depending on specific application.

Entry/Exit Connections:

- A wide variety of entry/exit connection configurations is possible, depending on spatial availability. Variations include exclusive AHS/mixed traffic flows and connections to the right or left hand side relative to the AHS lane.

- Conversion of an existing interchange ramp system to exclusive use by AHS (only) is possible if the spatial needs of check-in and check-out can be accommodated.

- Exclusive AHS lanes separated from non-AHS lanes by barriers will perform best with their own exclusive AHS ramp systems. Connections on the left side may be most cost effective if space permits this design.

- Exclusive AHS ramp systems are expected to minimize impact to the surface street if located at streets that do not have connections for non-AHS traffic causing congestion and additional traffic signals.

Transition Lanes:

- Exclusive AHS transition lanes offer the highest degree of safety, but require adequate width for installation.

- Transition lanes that allow mixed flow may work effectively in non-peak periods, but pose a merge and diverge dilemma during peak periods due to speed differentials between adjacent flows. This dilemma may be mitigated to some degree by using a buffer zone between the AHS lane and transition lane, but the buffer must be wide enough to accommodate a vehicle.

Frontage Roads:

- Frontage roads can help distribute traffic by offering an alternative to dealing with AHS traffic at the surface street interchange.

- Space between frontage roads and freeways may be used, where adequate width exists, to accommodate check-in and check-out facilities.

- Frontage roads may be constructed exclusively for the purpose of providing access to the AHS system.

Infrastructure

Instrumentation:

- Location and placement of instrumentation elements must consider safe and reasonable maintenance access, including provision for safe location of necessary maintenance vehicles.

- Instrumentation must be resistant to collisions, vandalism, and unauthorized access.

- Instrumentation location and placement must be tolerant of the environment, including temperature, moisture, and vibration.

Pavement Design:

- AHS lane and shoulder pavement should be designed to be more durable than existing pavement. Concrete, or an enhanced concrete design, may show the best promise.

- Pavement surfaces should provide friction factors, without deterioration over time, equal to or greater than existing freeways.

- Design techniques should account for elements necessary for access or otherwise creating surface seams, so that water seepage and resulting cracking and breakup is avoided.

- Pavement depth may be deeper, as a means of accounting for load concentrations along a single wheel path.

- System configurations utilizing pallets may require further research to determine pavement parameters to accommodate loadings and friction tolerances.

Drainage:

- Drainage design must remove water more quickly than existing design techniques to avoid degradation of AHS operations, at the higher speeds and higher safety factors to be provided.

- Surface condition sensors may be utilized to identify and advise the control system of potential system effects from moisture.

- Placement of drainage facilities outside the AHS area is desirable to minimize the negative impacts caused by maintenance or repair.

Communications Plant:

- Communications subsystems will consist of wireless systems providing communications between vehicles and roadside, and land line systems providing communications between roadside elements and central control centers.

- Advanced technologies, such as satellite and other hybrid systems, will become more available and cost effective as the technology matures.

- Designers must accommodate communications elements by providing reasonable and safe access for maintenance and repair and tolerance of the environment.

Traffic Control Devices:

- Traffic control devices will be required to convey messages to drivers relative to right-of-way assignment, to provide other information, and to assign position within the freeway cross section.

- Traffic control devices may consist of pavement markings, static and variable message signs, electrical lane signals, and traffic signals.

- The level of complexity of the traffic control devices subsystem will depend upon the AHS system concept deployed and its associated potential level of driver decision making and safety requirements.
- Traffic control device needs are most intensive where vehicles enter and exit the AHS lane or facility, with the urban operating environment offering the highest level of challenge.

Construction

Constructability:

- The constructability of any AHS facility on an existing freeway will require a case-by-case analysis of feasibility and identification of system concept options that can be reasonably accommodated.
- Some freeways will be able to accommodate AHS by conversion of existing space, such as HOV lanes, while in others AHS can only be accommodated in a mixed flow mode due to spatial constraints.
- Constructing additional lanes on the inside of an existing freeway cross section may be challenged by incompatible drainage slopes, spatial constraints, vertical and horizontal conflicts with existing structures, and the ability to locate accessible positions of the AHS support subsystems. Mitigations exist, but must be evaluated on the basis of cost effectiveness and disruption to the surrounding land uses.
- The construction of new entry and exit facilities may offer spatial availability challenges, but a variety of mitigation alternatives are possible on a site-by-site basis.

AHS Costs:

- The cost of the physical AHS lane construction is very site specific and RSC specific. In some cases the costs may be similar to those currently experienced by HOV construction, with the addition of the subsystem elements for communications and control.
- AHS construction cost depends heavily on the need to acquire right-of-way versus the ability to locate the AHS system within existing right-of-way. In some cases, it is anticipated that although the AHS may physically fit within the existing right-of-way, conflicts with other existing physical features may cause significant reconstruction of the entire cross section of the freeway.
- Deployment of AHS should include study of a set of alternative designs for a specific site and a comparison of the cost/benefit of each alternative.

Conversion Strategies:

- HOV lanes offer existing lane space for conversion to AHS. Some systems include exclusive HOV ramp systems and barriers compatible with some of the AHS concepts described in ongoing research.
- Use of existing lane space is a delicate issue and should be studied thoroughly for not only the roadway capacity issues, but the social impacts caused by the perception of taking away lane space on congested freeways.

Connectivity:

- Connections between multiple freeways providing exclusive AHS lanes should be continuous and allow smooth movement of AHS traffic between facilities without merging into non-AHS lanes to accomplish the route change.

Termination of AHS Facilities:

- Exclusive AHS lanes may begin or end between interchange points by widening the freeway cross section and appropriate tapering. This approach may be most effective in system concepts that do not utilize barriers to separate AHS and non-AHS flows, but requires on-the-fly check-in and check-out.
- Exclusive AHS lanes may begin or end at interchanges with ramp systems that terminate at a check-in/check-out facility or surface street. This approach is effective for system concepts that call for continuous longitudinal barriers between AHS and non-AHS lanes.

APPENDIX A

AUTOMATED HIGHWAY SYSTEMS
PRECURSOR SYSTEM ANALYSES
STATE DOT INPUT ELEMENT
ARIZONA DEPARTMENT OF TRANSPORTATION

APPENDIX A

AUTOMATED HIGHWAY SYSTEMS
PRECURSOR SYSTEM ANALYSES
STATE DOT INPUT ELEMENT
ARIZONA DEPARTMENT OF TRANSPORTATION

A workshop was conducted for the Arizona Department of Transportation on 15 April, 1994 at the offices of BRW, Inc. in Phoenix, Arizona. The purpose of this workshop was to solicit input and comment on the deployment of an Automated Highway System (AHS) as part of the research efforts associated with the FHWA's Precursor System Analysis. BRW is participating in this program as a component of a project research team lead by the Battelle Foundation, of Columbus, Ohio.

The following issues were identified by participants as critical in consideration of AHS deployment:

- Ramp systems serving the entry/exit functions of the AHS could assumably be located at less frequent intervals than today's ramp spacing in urban areas. However, a close examination should be conducted of the effect of closing an AHS interchange on adjacent AHS interchanges from a congestion concentration perspective. A traffic management plan is suggested to be developed for specific implementation sites to address how to redirect AHS entry/exit traffic to avoid over concentration at any one interchange.

- A strong recommendation was made to always separate AHS and non-AHS traffic lanes through the use of a positive barrier in any concept that provides exclusive AHS lanes.

- A strong concern was expressed for maintaining a high level of security of the AHS system from non-AHS intruders in design concepts that utilize exclusive AHS lanes. Assuming barriers are used to segregate the traffic streams, this security concern was intended to relate to the entry process as the point at which this filtering of traffic would be applicable.

- In a mixed traffic concept in which AHS and non-AHS traffic share a lane, such as a rural operating environment between cities where addition of lanes would be too costly, it was predicted that while AHS traffic is located in the left lane, non-AHS traffic would be allowed to enter and use the left lane for passing. It was suggested that a high level of enforcement may be necessary to prohibit aggressive non-AHS drivers from attempting to travel long distances in the left lane by trying to keep pace with AHS vehicles.

- In a design concept that precluded the use of positive barriers between AHS and non-AHS lanes, a buffer space should be striped between the two traffic streams. This buffer should be at least two ft in width, and wider where space allows. A buffer space more than four ft in width should have a striping element, such as a chevron, located on the pavement to reinforce the idea that it is a reserved buffer space.

- Conversion of an existing HOV lane may be tough to sell to the public. Design concepts should consider AHS lanes plus HOV lanes where space permits.

- Any design concept intended for use with semi-trailer tractors should consider the dynamic differences of that type of vehicle, especially if higher than normal operating speeds are anticipated. Stopping distances may require special strategies for headways.

- A concern was voiced over the higher speeds, and thus assumably higher speed limits associated with AHS. It was felt that higher speeds in the AHS lanes will psychologically encourage higher travel speeds in adjacent non-AHS lanes when traffic conditions allow, presenting a safety and enforcement concern.

- It was perceived that since AHS is being presented as a technique for single vehicles such as automobiles (at least in this project team's Precursor System Analysis assumption set), that the public may perceive the AHS as focusing too much on the promotion of single vehicles while strategies such as HOV lanes focus on the promotion of moving higher numbers of people. This issue may be important in the debate of converting an existing HOV lane to AHS.

- Conditions in Arizona generally allow plenty of spacial availability for construction of new lanes, and that ADOT would be very interested in participating in an early field deployment of AHS.

APPENDIX B

AUTOMATED HIGHWAY SYSTEMS
PRECURSOR SYSTEM ANALYSIS
STATE DOT INPUT ELEMENT
TEXAS DEPARTMENT OF TRANSPORTATION

APPENDIX B

AUTOMATED HIGHWAY SYSTEMS
PRECURSOR SYSTEM ANALYSIS
STATE DOT INPUT ELEMENT
TEXAS DEPARTMENT OF TRANSPORTATION

A workshop was conducted for the Texas Department of Transportation on 25 May, 1994 at the offices of the Texas Department of Transportation (TxDOT) in San Antonio, Texas. The purpose of this workshop was to solicit input and comment on the deployment of an Automated Highway System (AHS) as part of the research efforts associated with the FHWA's Precursor System Analysis. BRW is participating in this program as a component of a project research team lead by the Battelle Foundation, of Columbus, Ohio.

The following issues were identified by participants as critical in consideration of AHS deployment:

·A tour of the new Traffic Operations Center (TOC) was conducted for the BRW staff attendees to gain a perspective on how the new TOC could function with the AHS in terms of operational control strategies. Such elements are being researched by Cheryl McConnell, of BRW, under the Operational Issues task of this project.

·The concept of having a mixed flow situation, where AHS and non-AHS vehicles occupy the same lane has a problem providing the capacity enhancements desired from AHS operations simply because no AHS vehicle can go any faster than a non-AHS vehicle in the same lane. In cities such as San Antonio, Houston, Dallas or Austin, congestion during peak hours mean that the AHS vehicles would be subject to very slow travel speeds. However, a rural application of mixed flow shows promise and seems to be a good approach to keeping the cost down by eliminating the need for new lanes. Mixed flow conditions might provoke safety concerns, more from the perspective of the non-AHS vehicles making erratic lane changes, affecting AHS safety.

·TxDOT's observation of the evolution of the entire AHS system is that the time it will take will be very long. Recognizing that the technology does exist now, political, institutional and financial concerns appear to be the biggest hurdles.

·Satellite communications should be looked at as a means of overall system communications. This may allow a more consistent communications architecture as opposed to relying on a more regional architecture that may be different between areas.

·TxDOT commented on the smart infrastructure approach. Although it would imply a significant impact on the Department in terms of maintenance and operational responsibility, it would minimize the equipment in the vehicle, thus allowing quicker market penetration and public acceptance.

·It would be desirable, from a financial perspective, for the drivers on the AHS system to help pay the cost. This could be through tolls or other cost mitigation methods.

·TxDOT is very interested in being an early deployment test site for AHS.

·Department staff liked the idea of having barriers separating AHS traffic from non-AHS traffic. This could be done by exclusive entry/exit facilities, or by using right-hand entry/exit facilities and seeking gaps in the barrier, similar to the PATH concept. Blunt barrier ends would need to be highly protected and the location of the barrier gaps will need to be thought out to avoid creating side friction at locations where its effect would devastate operations. Barrier gaps would not have to be one per entry/exit, and could be located strategically to minimize safety and friction problems.

·TxDOT noted that the "Bubba factor" would be expected to be high in their area of operation from non-AHS vehicles using exclusive AHS lanes for passing maneuvers and then slipping back into non-AHS lanes. Thus, barriers between AHS and non-AHS as well as some sort of security measures to minimize or eliminate non-AHS intrusions.

·Ideal AHS system configuration would be to have the AHS lanes with exclusive entry/exit system, all completely segregated from non-AHS lane systems by barriers. This would allow high speeds and guarantee safety from intrusions.

·The major problem observed with a design which features AHS lanes which have to cross non-AHS lanes for entry/exit is that the speeds in adjacent lanes would need to be compatible. Thus, either transition lanes would be constructed, if space allows, or AHS vehicles would need to reduce speed in AHS lanes to match adjacent non-AHS lanes for exit. Entry would have similar problems with AHS vehicles accelerating to high speeds in non-AHS lanes, causing a safety issue to non-AHS vehicles and giving non-AHS drivers the sense that it is ok to drive faster than the speed limit because their neighbor was observed doing so.

·Suggest hierarchy of design concepts:

1. Exclusive AHS ramps and lanes with barriers.
2. Mixed ramps, exclusive AHS travel lanes.
3. Mixed ramps and mixed flow lanes.
4. Non-AHS (likely in many areas due to space or operational constraints).

·Emphasis on any design strategy should be on safety first and foremost.

- ·All AHS shoulders should be wide enough to drive on for emergency access or to avoid disabled vehicles in AHS lanes.

- ·Staff was very worried about the handling of and frequency of incidents. Their experience has been that even though the new TOC will be programmed to handle over 62,000 different types and locations of incidents, they recognize that “new” types of incidents will always come up and AHS will add to that new category. Thus, manual interface and management of incidents is expected to be a priority in terms of operations.

- ·In design, try to match the maintenance burden of AHS with a reasonable assessment of the maintenance abilities of State DOTs. This would be an argument for a less infrastructure intensive design.

- ·Pavement should be designed for all weather conditions, possibly with devices for melting snow and sensing pavement surface conditions.

- ·If the magnetic nails method were used, staff questioned if the pavement could ever be overlaid and the nails still serve their purpose effectively.

- ·Any infrastructure components requiring maintenance must be located such that maintenance personnel are not subject to undue safety hazards.

- ·In general success of AHS, program will need to create the need for “Joe Public” to want to support and use AHS. The public tends to like free systems (no cost). In San Antonio, the ATMS system has been met with great public support because the public thinks it is free to them because they have not been asked to pay additional taxes or to institute tolls.

- ·Conversion of an entire freeway to AHS seems to have merit. This would avoid the confusion of AHS and non-AHS operation in the same cross section. However, the practicality of this approach may not be appropriate, at least in the early stages. Perhaps abandoned rail right-of-ways could be utilized for some intercity routes.

- ·Conversion of existing lanes would be expected to be a big issue when trying to convince public to support AHS in early stages. Some sort of strategy to sell AHS seems to be needed. In Houston, for example, HOV lanes are heavily used by the bus company. Conversion of those HOV lanes would be a huge political struggle.

- ·Biggest hurdle: Public acceptance and support.

APPENDIX C

SITE SPECIFIC ANALYSES

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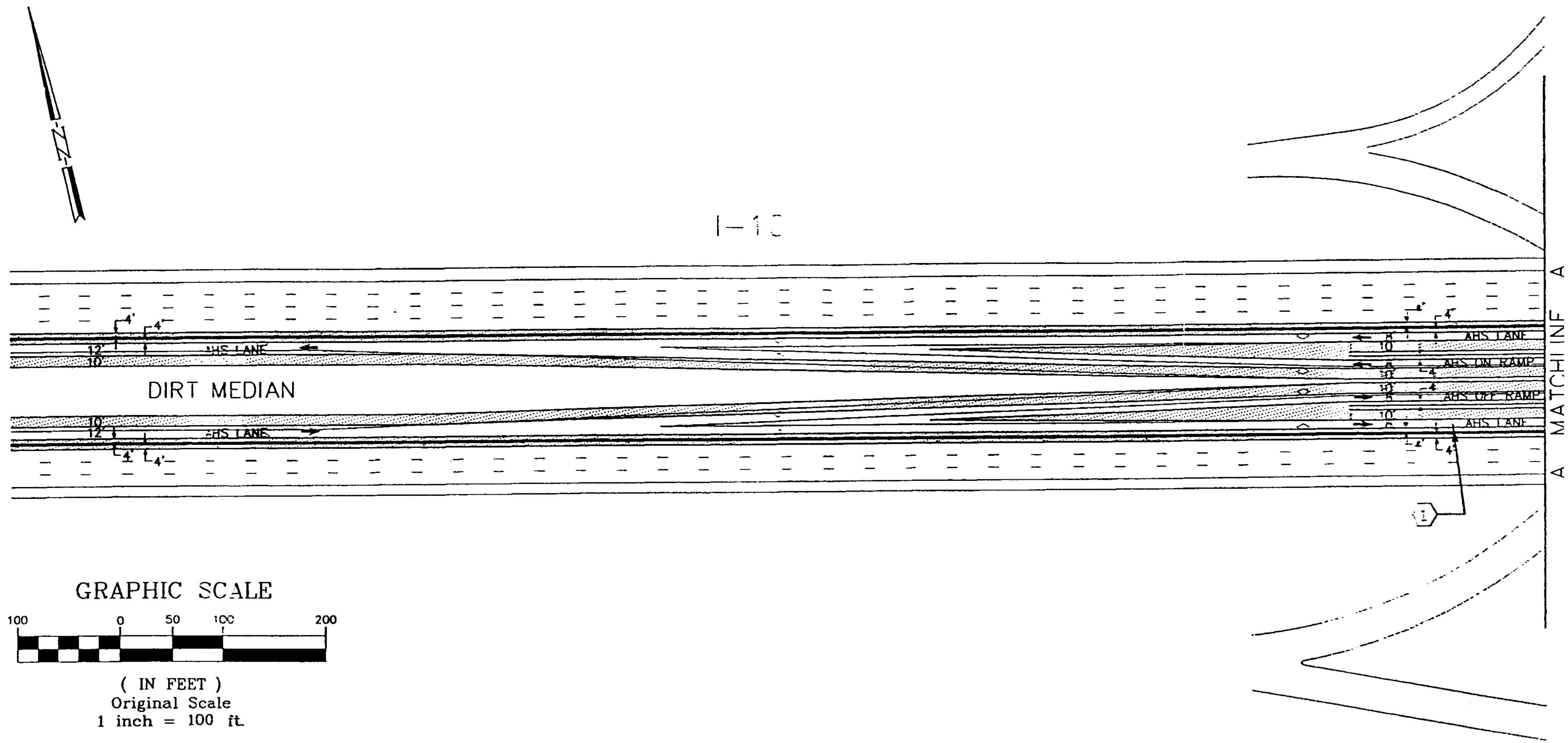

LEGEND

- DENOTES SHOULDER AREA

SHEET SPECIFIC ISSUES

(1) – 10' FREEWAY SHOULDERS ARE DESIRABLE WITH 3 OR MORE LANES DIRECTIONALLY. 8' IS MINIMUM FOR AHS LANES. AHS LANES WIDER THAN 8' OR SHOULDERS WIDER THAN 4' WOULD REQUIRE FREEWAY WIDENING, ALTHOUGH AN 11' AHS LANE WITH A ONE FOOT RIGHT SHOULDER AND A 10 FOOT LEFT SHOULDER WOULD BE VIABLE.

PROJECT ISSUES

- IMPACTS THAT INVOLVE WIDENING OF THE MAINLINE FREEWAY INCLUDE THE FOLLOWING:
  - RETAINING WALL ADJUSTMENT
  - DRAINAGE MODIFICATIONS
  - LANDSCAPING MODIFICATIONS
  - VERTICAL CLEARANCES AT OVERPASS STRUCTURES
  - STRUCTURE CONFLICTS ie; PIERS, ABUTMENTS AND SLOPE PAVING
  - RAMP REALIGNMENT
  - NOISE WALL CONSTRUCTION FOR AREAS CURRENTLY WITHOUT NOISE WALLS
- IMPACTS THAT INVOLVE WIDENING OF THE AHS LANE STRUCTURES INCLUDE THE FOLLOWING:
  - MAINLINE FREEWAY WIDENING (SEE ABOVE)
  - INTERSECTION AND SIGNAL MODIFICATIONS AT OVERPASS INTERSECTIONS

DATE: 9/21/94	SHEET 1 OF 10 SHEETS	DWG REF: PHXSHT1
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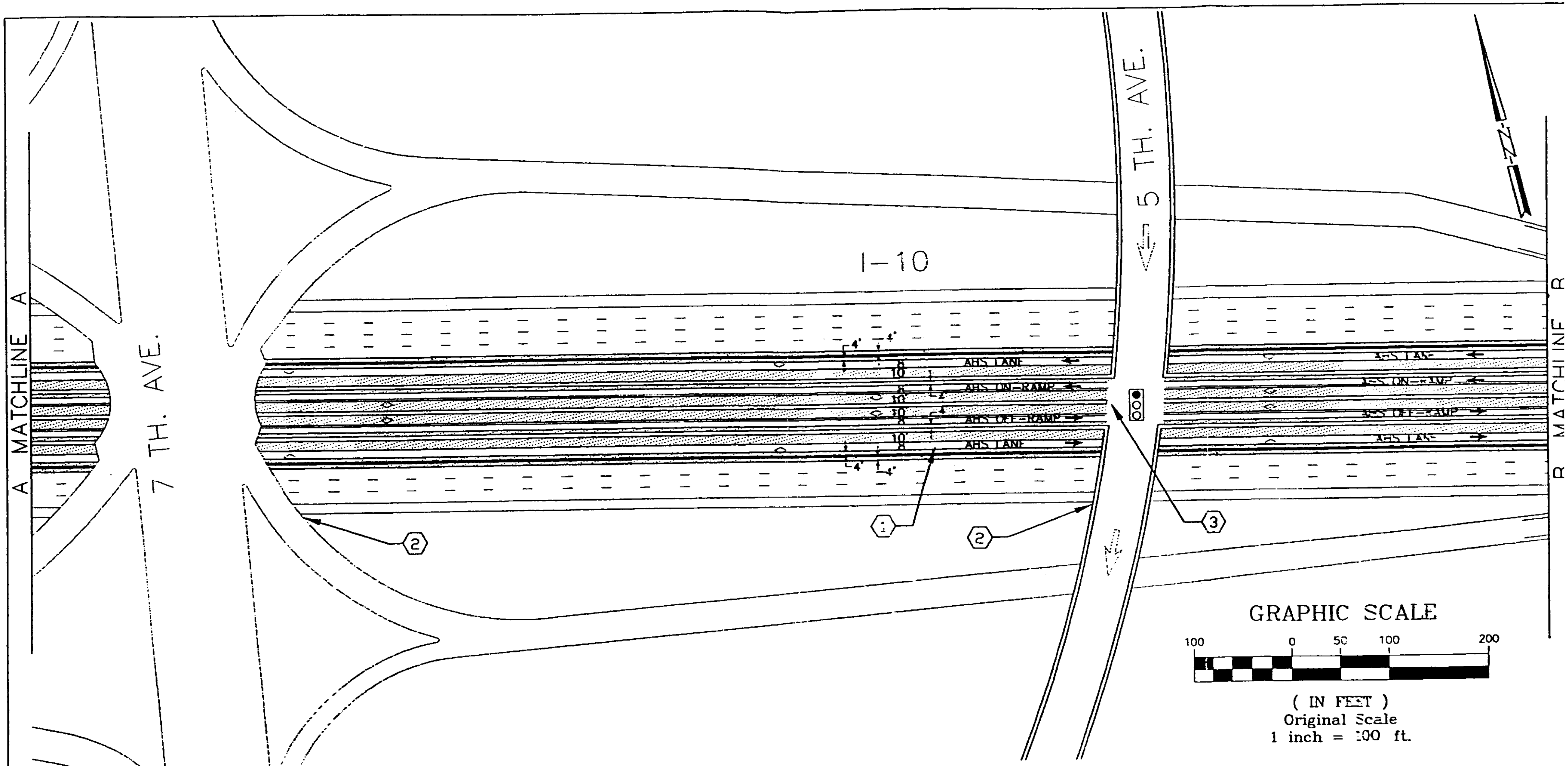

LEGEND

- DENOTES SHOULDER AREA
- SIGNALIZED INTERSECTION

ISSUES

1. – 10' FREEWAY SHOULDERS ARE DESIRABLE WITH 3 OR MORE LANES DIRECTIONALLY. 8' IS MINIMUM FOR AHS LANES. AHS LANES WIDER THAN 8' OR SHOULDERS WIDER THAN 4' WOULD REQUIRE FREEWAY WIDENING, ALTHOUGH AN 11' AHS LANE WITH A ONE FOOT RIGHT SHOULDER AND A 10 FOOT LEFT SHOULDER WOULD BE VIABLE.
2. – WIDENING WOULD CREATE POTENTIAL CONFLICTS WITH OVERPASS STRUCTURE PIERS, ABUTMENTS OR SLOPE PAVING. WIDENING WOULD ALSO IMPACT ON/OFF RAMP ALIGNMENTS.
3. – GENERAL TRAFFIC WILL BE PREVENTED FROM ENTERING AHS LANES VIA CHECK-IN FACILITIES.

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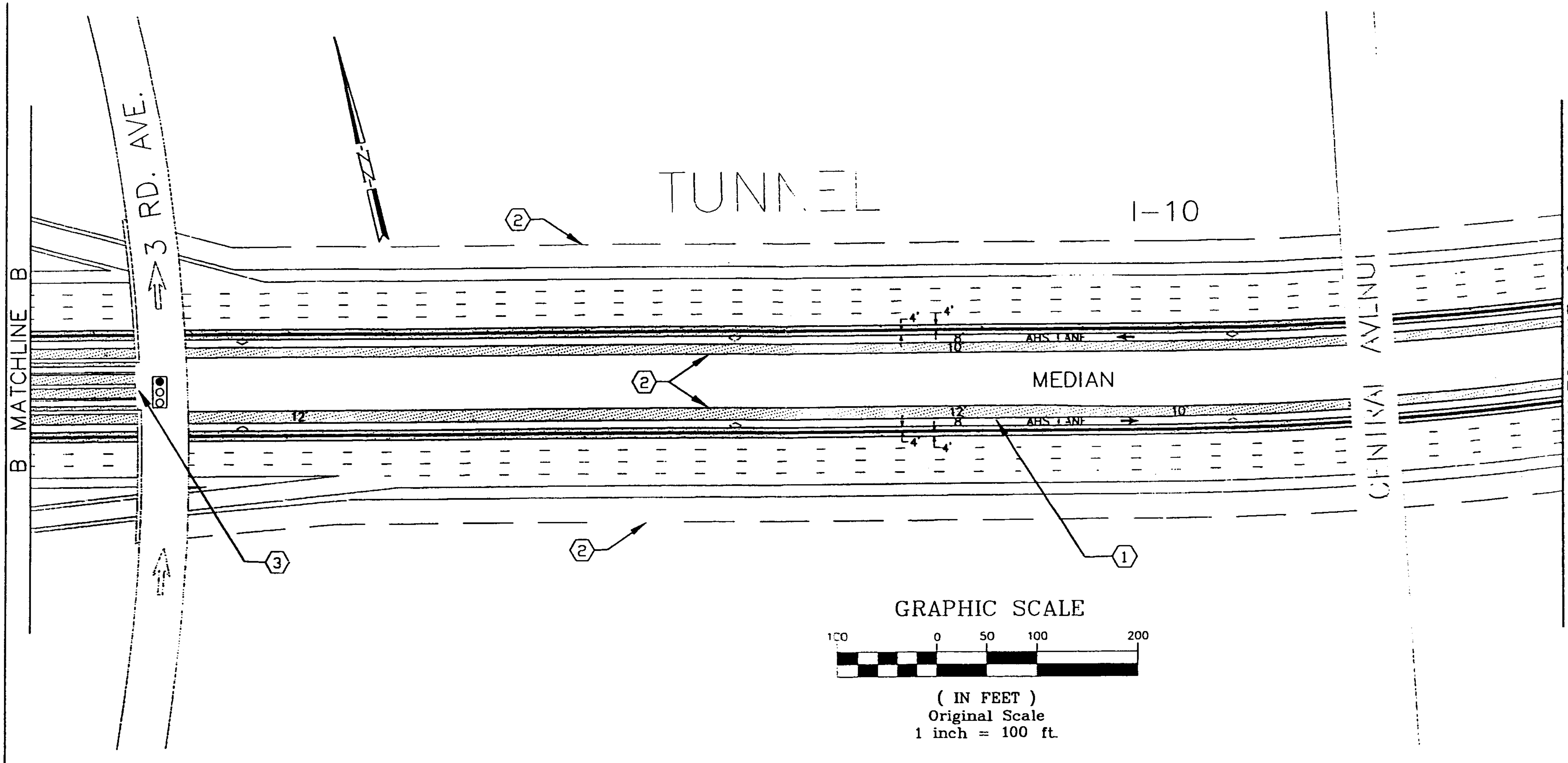

LEGEND

- DENOTES SHOULDER AREA
- SIGNALIZED INTERSECTION

ISSUES

(1) – 10' FREEWAY SHOULDERS ARE DESIRABLE WITH 3 OR MORE LANES DIRECTIONALLY. 8' IS MINIMUM FOR AHS LANES. AHS LANES WIDER THAN 8' OR SHOULDERS WIDER THAN 4' WOULD REQUIRE FREEWAY WIDENING, ALTHOUGH AN 11' AHS LANE WITH A ONE FOOT RIGHT SHOULDER AND A 10 FOOT LEFT SHOULDER WOULD BE VIABLE.

(2) – TUNNEL WALLS PREVENT WIDENING TO ACCOMODATE DESIRED WIDTHS FOR ALL LANES AND SHOULDERS.

(3) – GENERAL TRAFFIC WILL BE PREVENTED FROM ENTERING AHS LANES VIA CHECK-IN FACILITIES.

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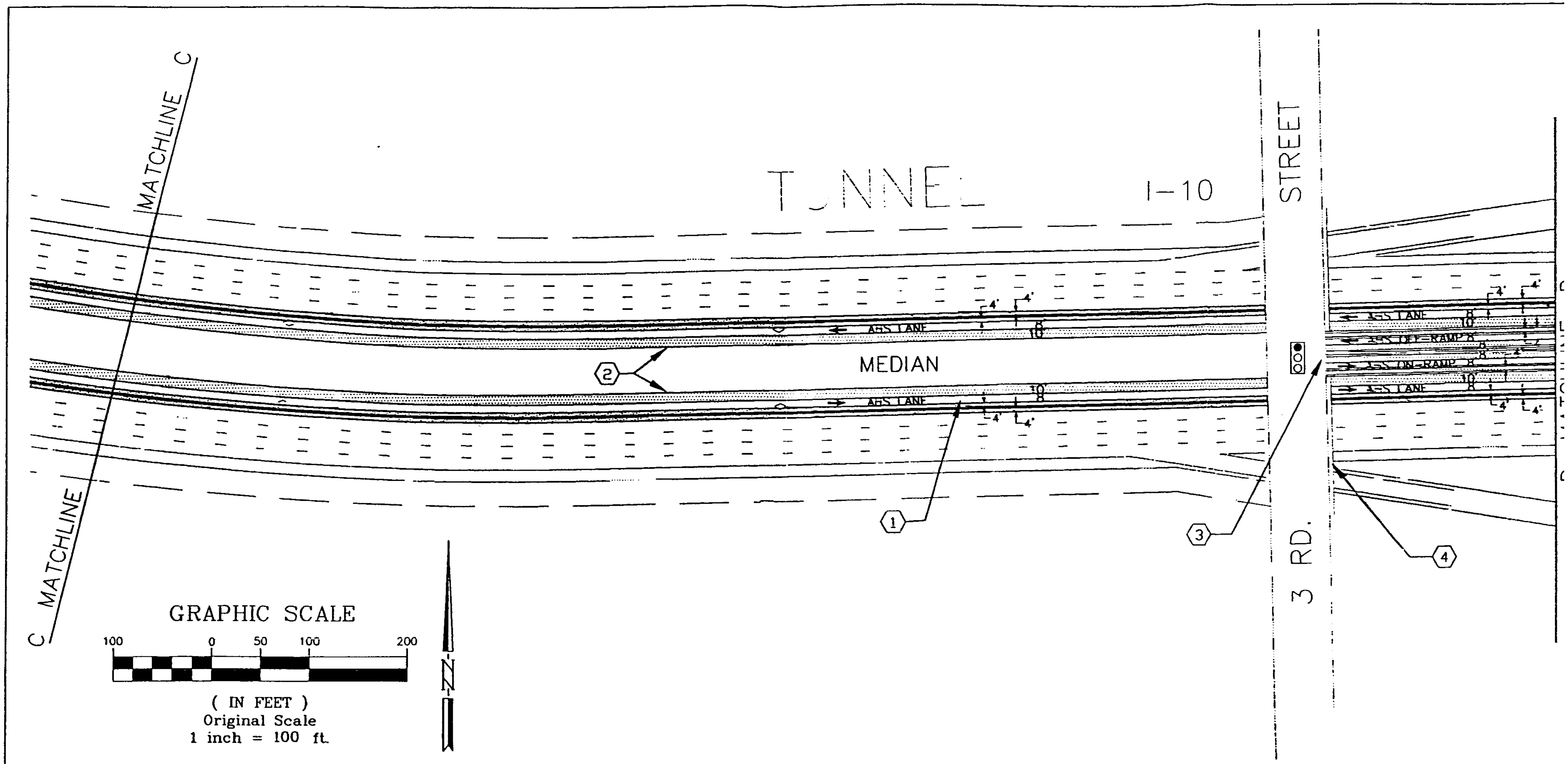

LEGEND

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[signal symbol] – SIGNALIZED INTERSECTION

ISSUES

1 – 10' FREEWAY SHOULDERS ARE DESIRABLE WITH 3 OR MORE LANES DIRECTIONALLY. 8' IS MINIMUM FOR AHS LANES. AHS LANES WIDER THAN 8' OR SHOULDERS WIDER THAN 4' WOULD REQUIRE FREEWAY WIDENING, ALTHOUGH AN 11' AHS LANE WITH A ONE FOOT RIGHT SHOULDER AND A 10 FOOT LEFT SHOULDER WOULD BE VIABLE.

2 – TUNNEL WALLS PREVENT WIDENING TO ACCOMODATE DESIRED WIDTHS FOR ALL LANES AND SHOULDERS.

3 – GENERAL TRAFFIC WILL BE PREVENTED FROM ENTERING AHS LANES VIA CHECK-IN FACILITIES.

4 – WIDENING WOULD CREATE POTENTIAL CONFLICTS WITH OVERPASS STRUCTURE PIERS, ABUTMENTS OR SLOPE PAVING. WIDENING WOULD ALSO IMPACT ON/OFF RAMP ALIGNMENTS.

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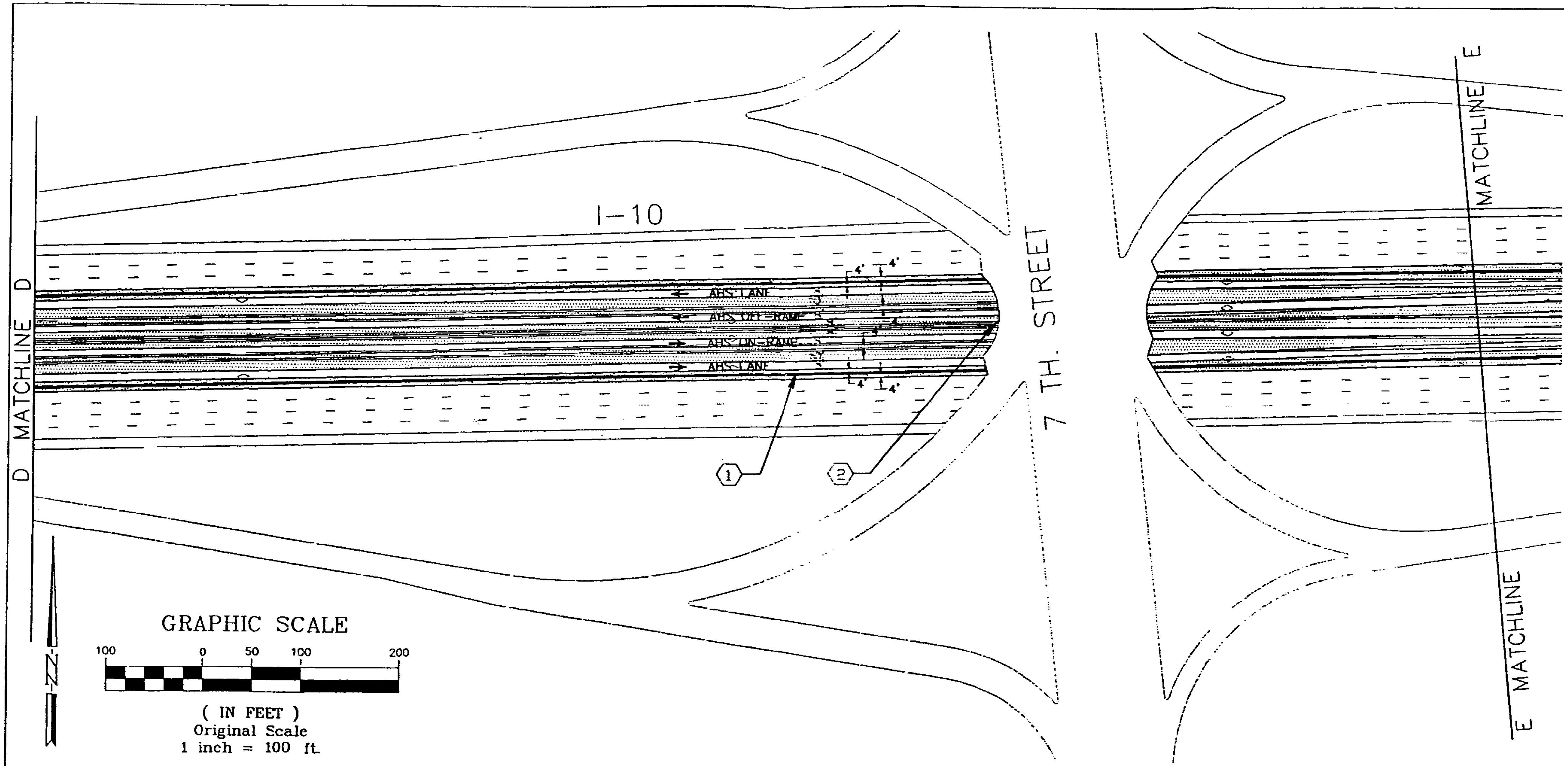

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ISSUES

(1) – 10' FREEWAY SHOULDERS ARE DESIRABLE WITH 3 OR MORE LANES DIRECTIONALLY. 8' IS MINIMUM FOR AHS LANES. AHS LANES WIDER THAN 8' OR SHOULDERS WIDER THAN 4' WOULD REQUIRE FREEWAY WIDENING, ALTHOUGH AN 11' AHS LANE WITH A ONE FOOT RIGHT SHOULDER AND A 10 FOOT LEFT SHOULDER WOULD BE VIABLE.

(2) – WIDENING WOULD CREATE POTENTIAL CONFLICTS WITH OVERPASS STRUCTURE PIERS, ABUTMENTS OR SLOPE PAVING. WIDENING WOULD ALSO IMPACT ON/OFF RAMP ALIGNMENTS.

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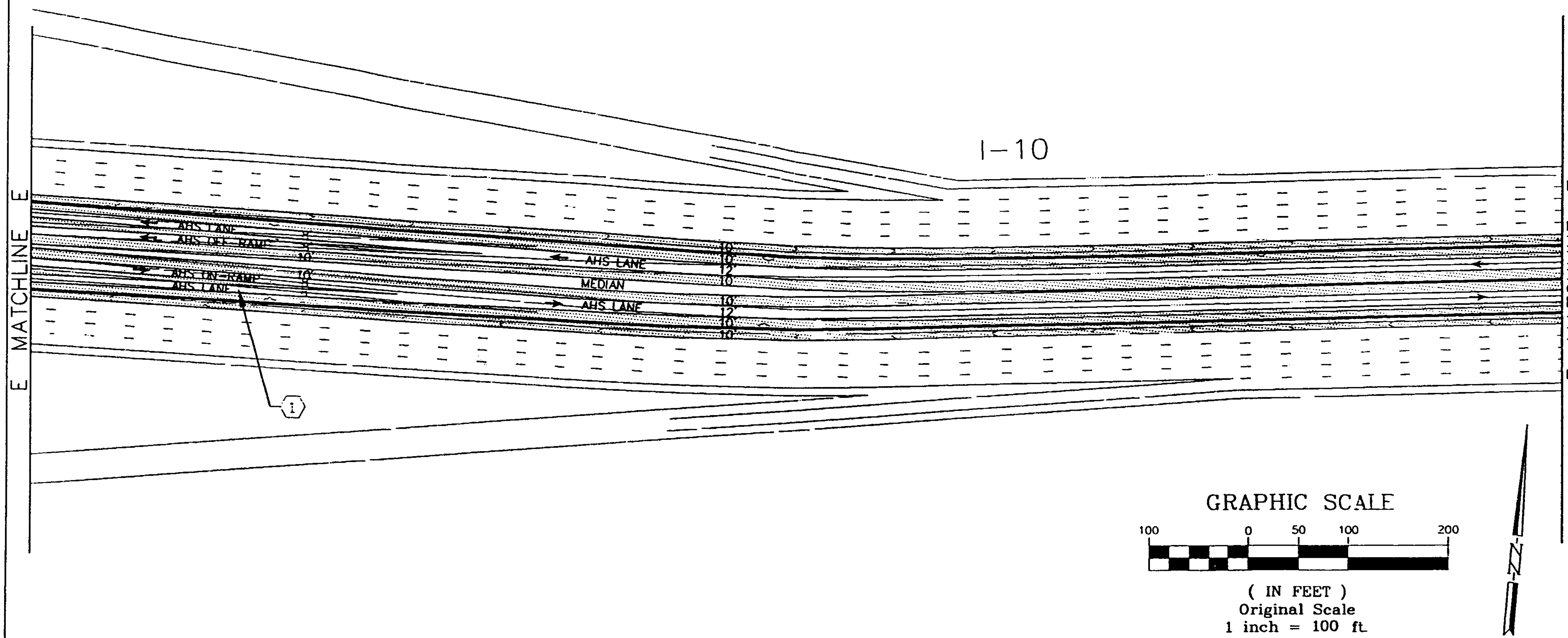

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ISSUES

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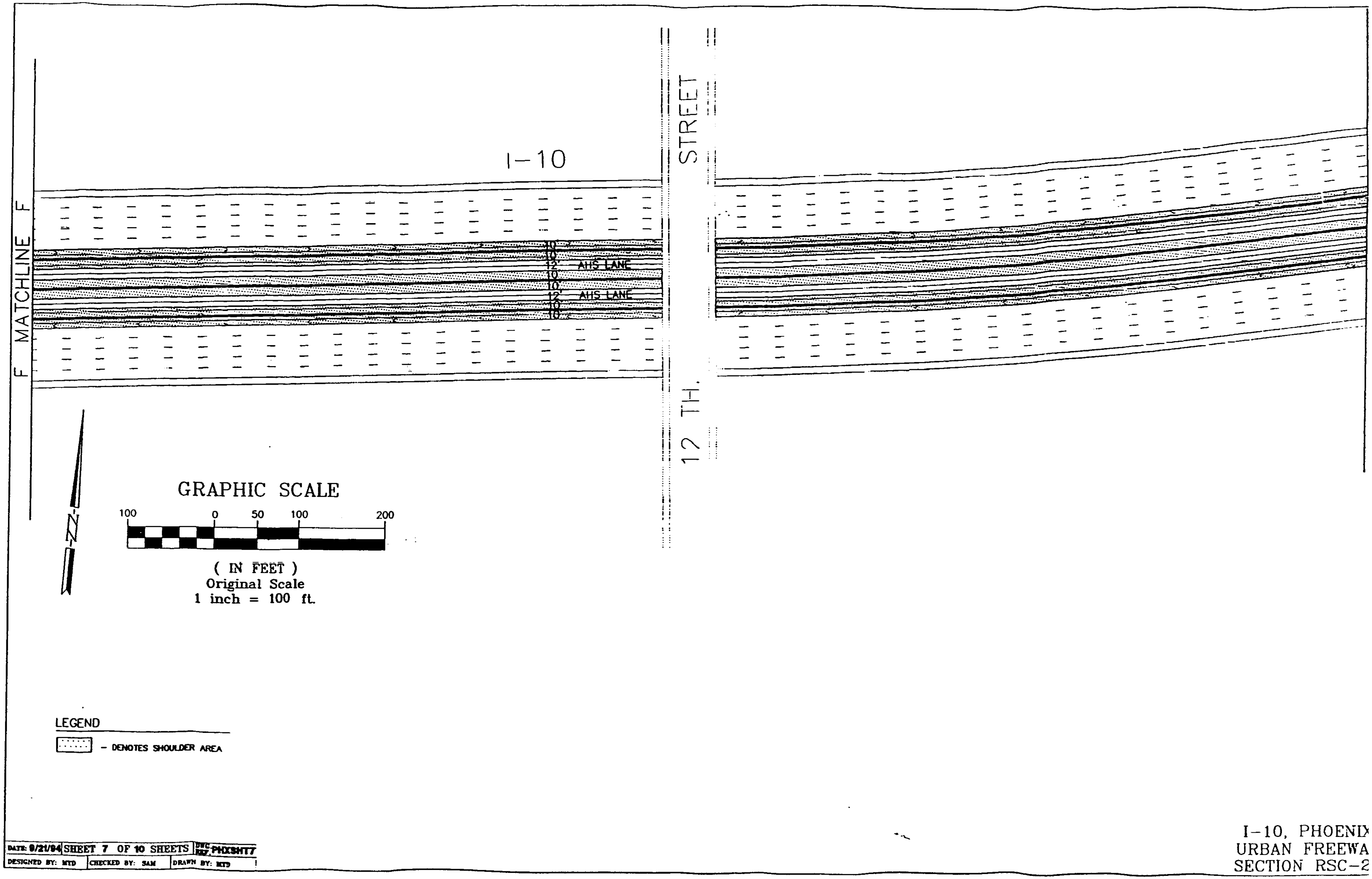
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I-10, PHOENI
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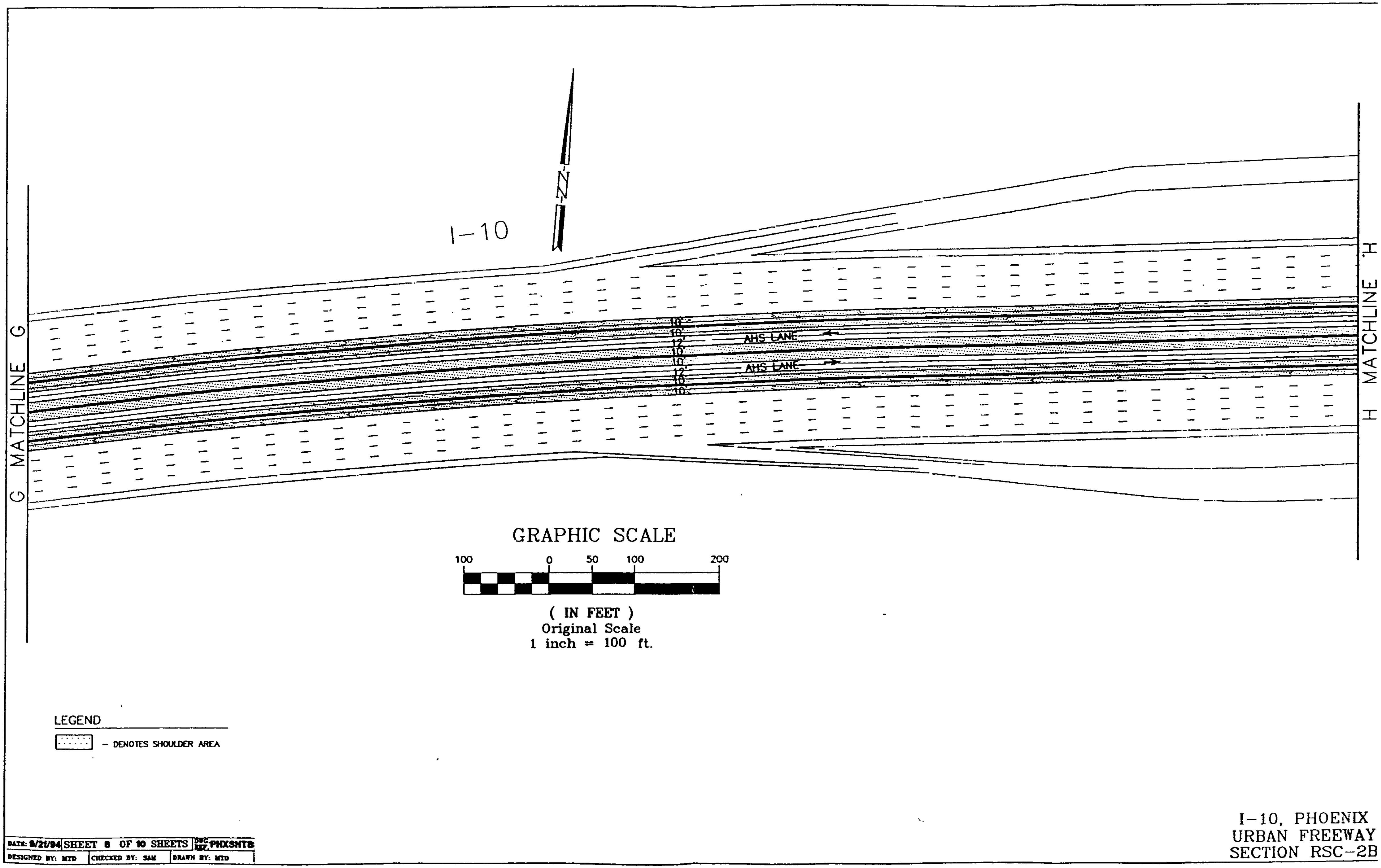
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1 inch = 100 ft.
LEGEND
- DENOTES SHOULDER AREA
DATE: 9/21/94
SHEET 8 OF 10 SHEETS
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URBAN FREEWAY
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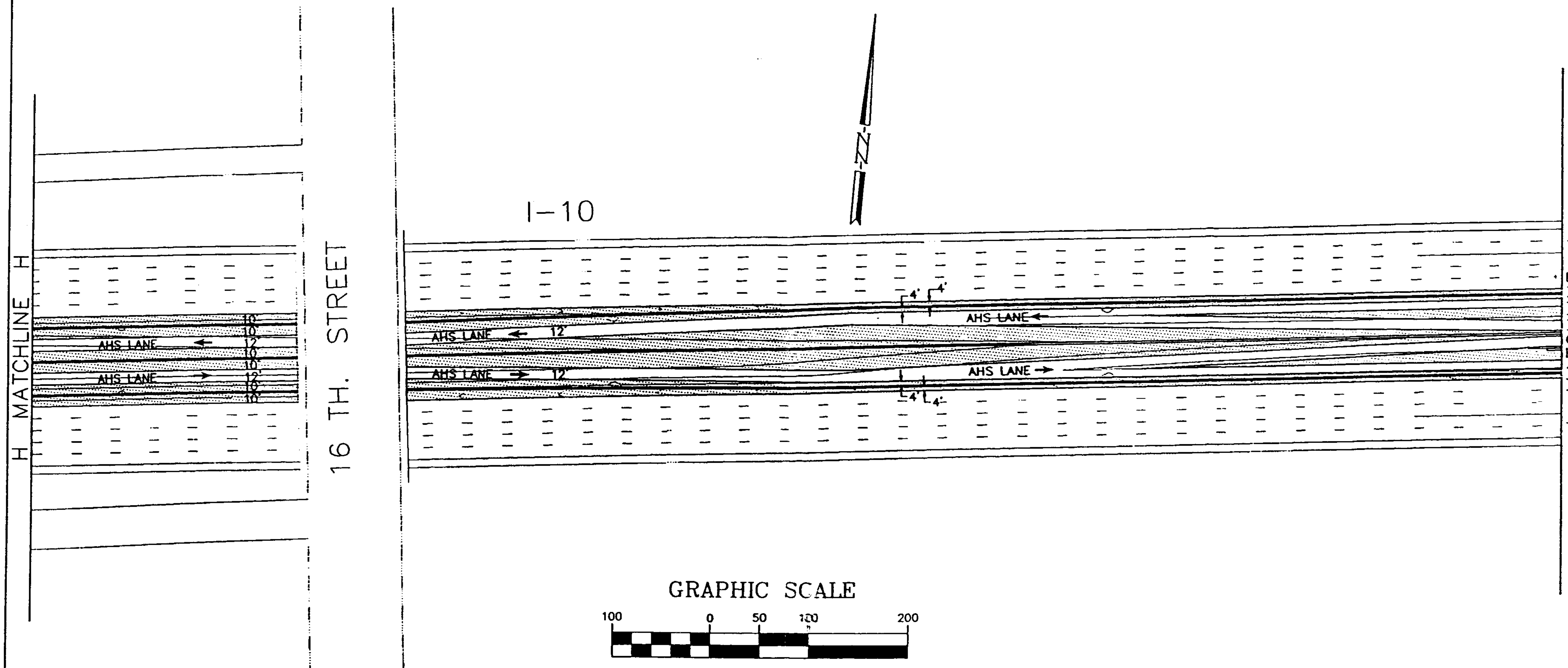

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1 inch = 100 ft.

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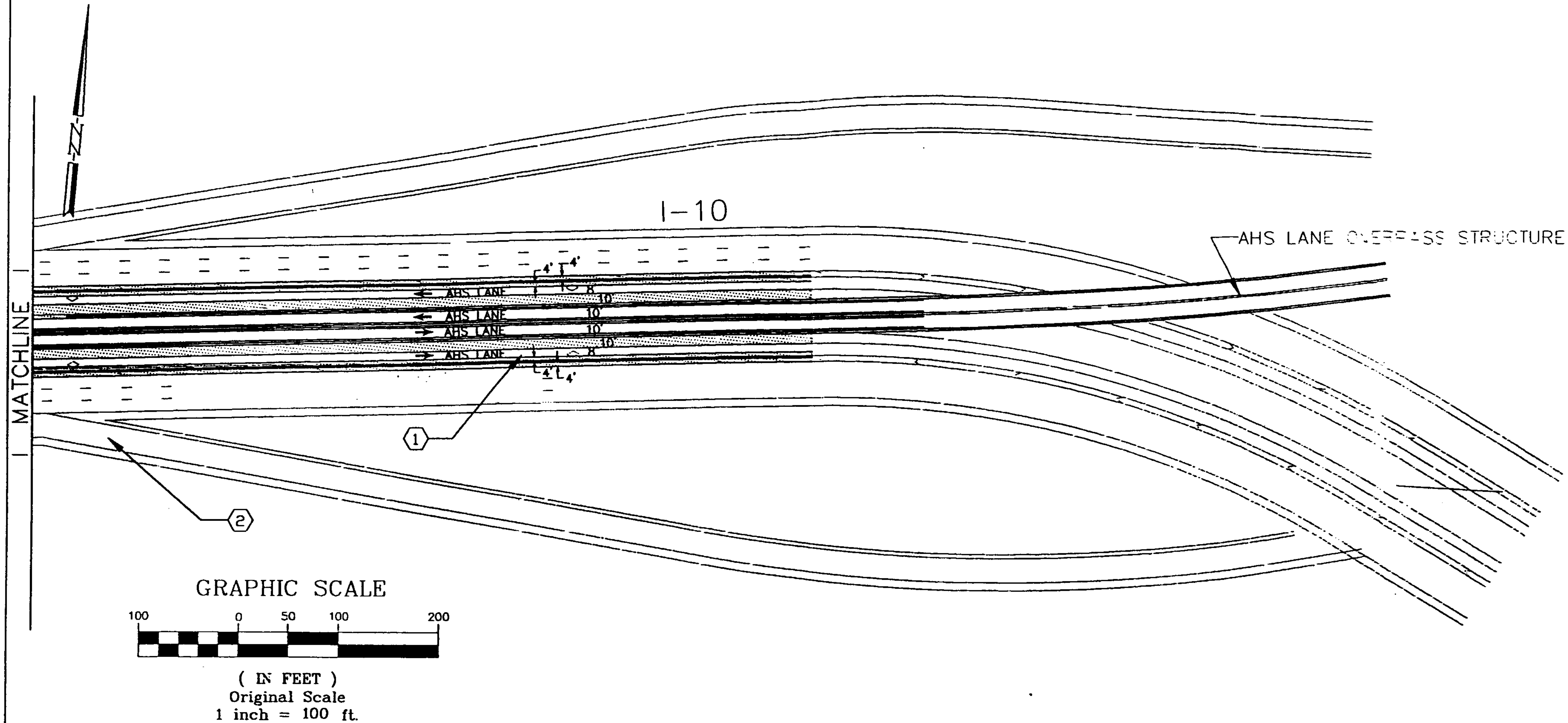

LEGEND

- DENOTES SHOULDER AREA

ISSUES

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(2) – WIDENING WOULD CREATE POTENTIAL CONFLICTS WITH OVERPASS STRUCTURE PIERS, ABUTMENTS OR SLOPE PAVING. WIDENING WOULD ALSO IMPACT ON/OFF RAMP ALIGNMENTS.

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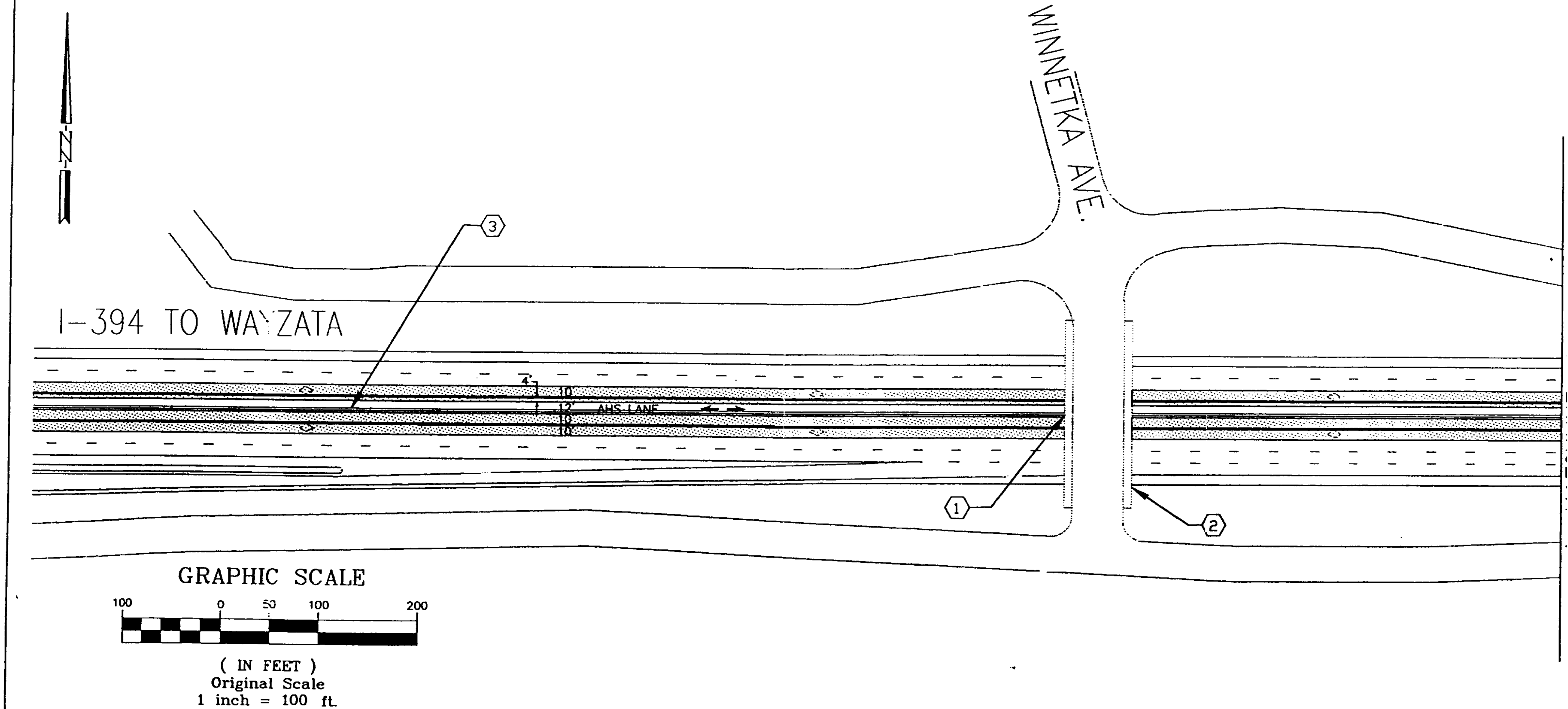

LEGEND

- DENOTES SHOULDER AREA

ISSUES

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(2) - WIDENING MAY CONFLICT WITH OVERPASS STRUCTURE ELEMENTS SUCH AS PIERS, ABUTMENTS OR SLOPE PAVING.

(3) - REMOVE EXISTING BARRIER.

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I-394, MINNEAPOLIS TO WAYZATA
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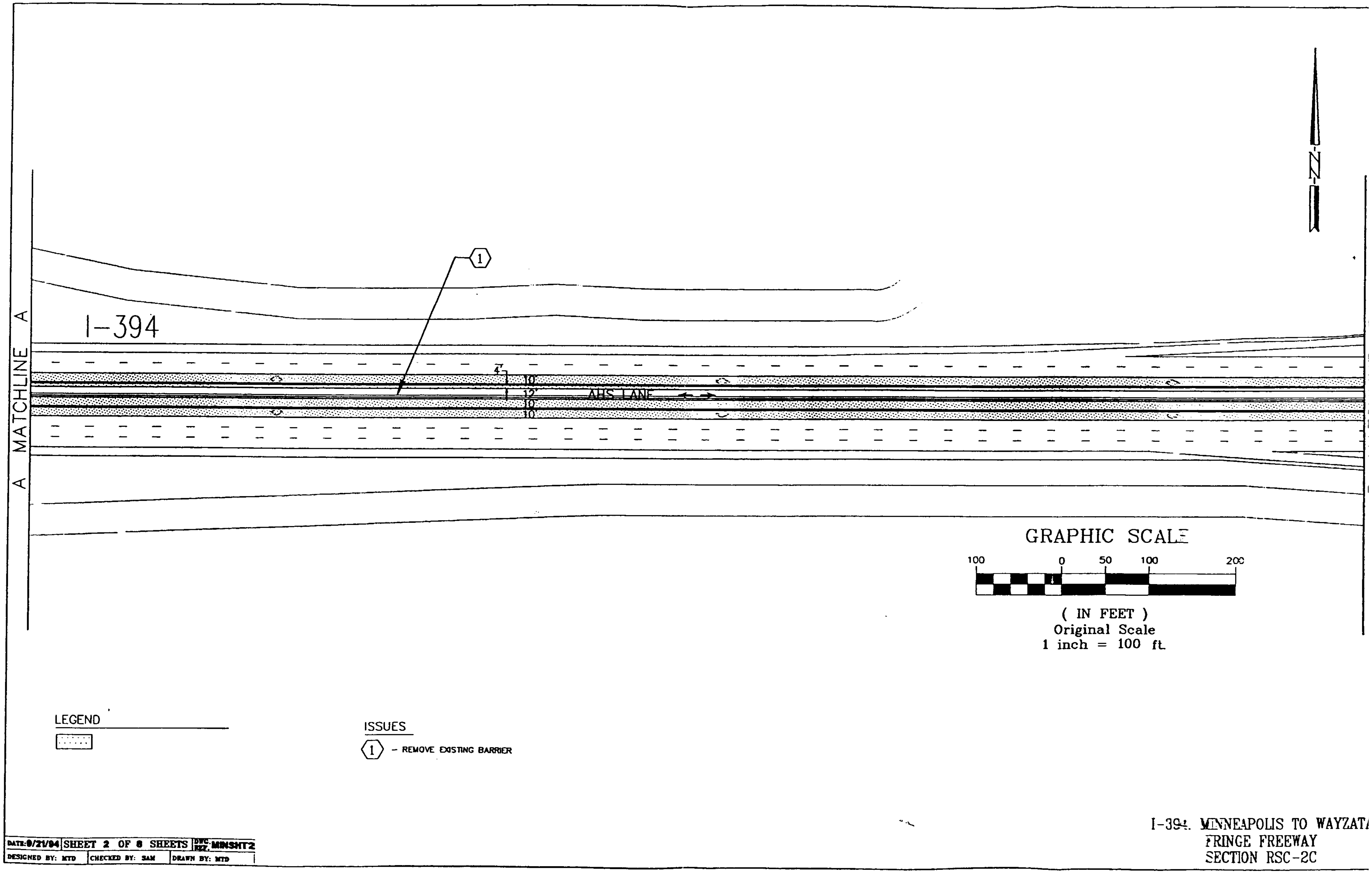
SECTION RSC-2C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DATE: 9/21/94
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FRINGE FREEWAY
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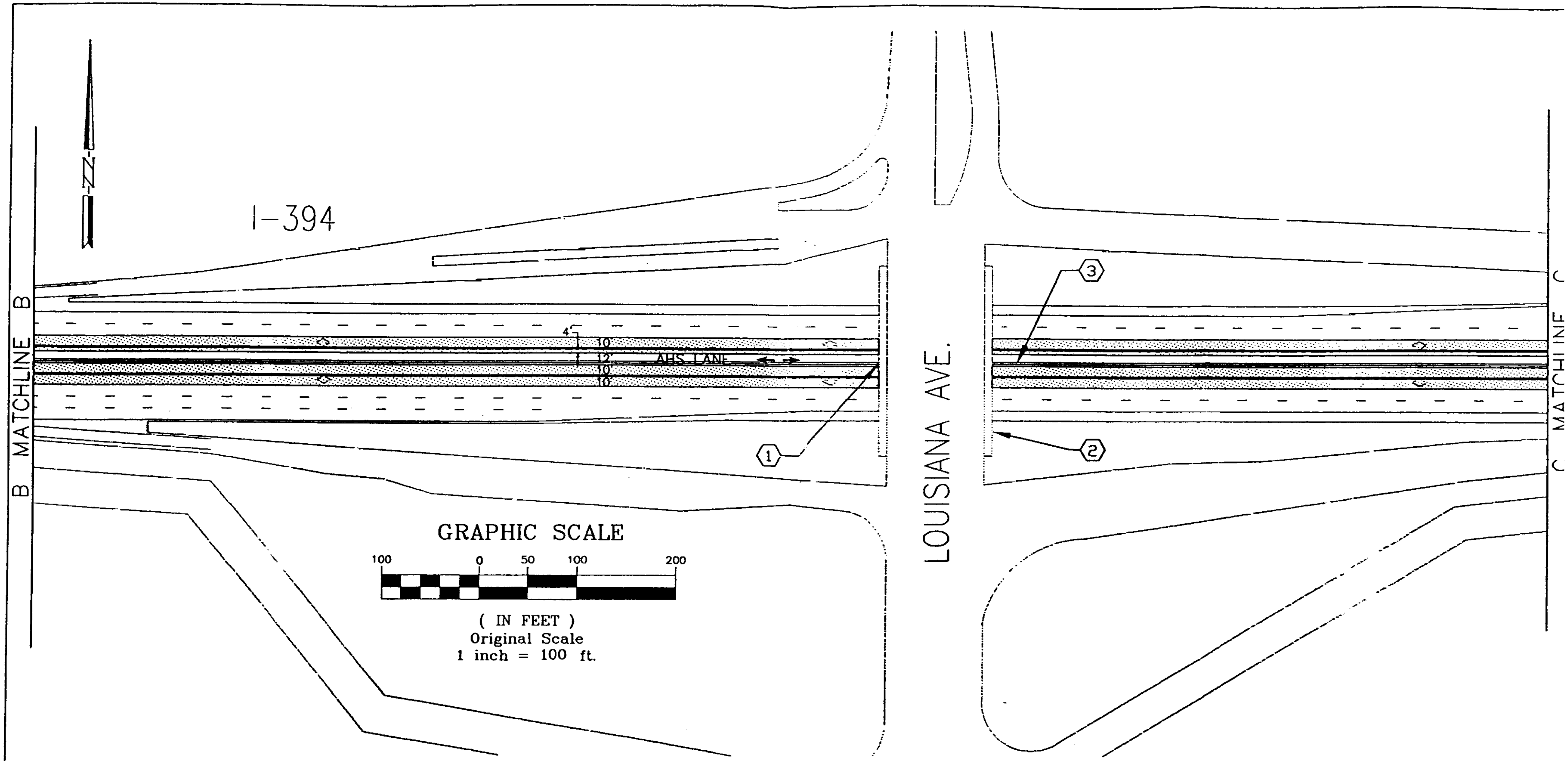

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ISSUES

1. – POTENTIAL CONFLICT WITH CENTER PIER OF OVERPASS STRUCTURE. MAY NEED TO WIDEN AND/OR REALIGN FREEWAY APPROACHING PIER.
2. – WIDENING MAY CONFLICT WITH OVERPASS STRUCTURE ELEMENTS SUCH AS PIERS, ABUTMENTS OR SLOPE PAVING.
3. – REMOVE EXISTING BARRIER

DATE: 9/21/94	SHEET 3 OF 8 SHEETS	DWG. REF. MINSHTS
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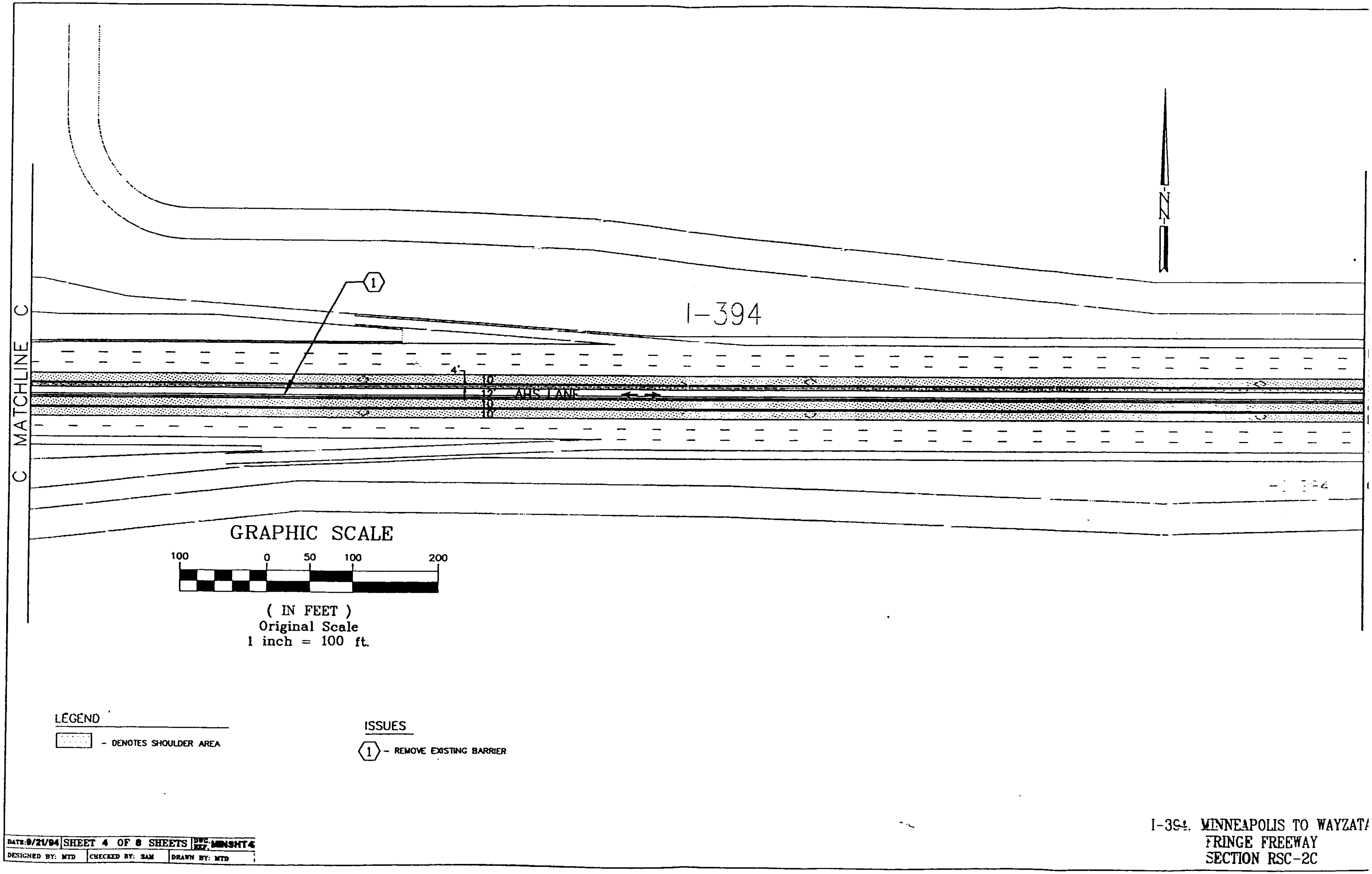
I-394. MINNEAPOLIS TO WAYZATA
FRINGE FREEWAY
SECTION RSC-2C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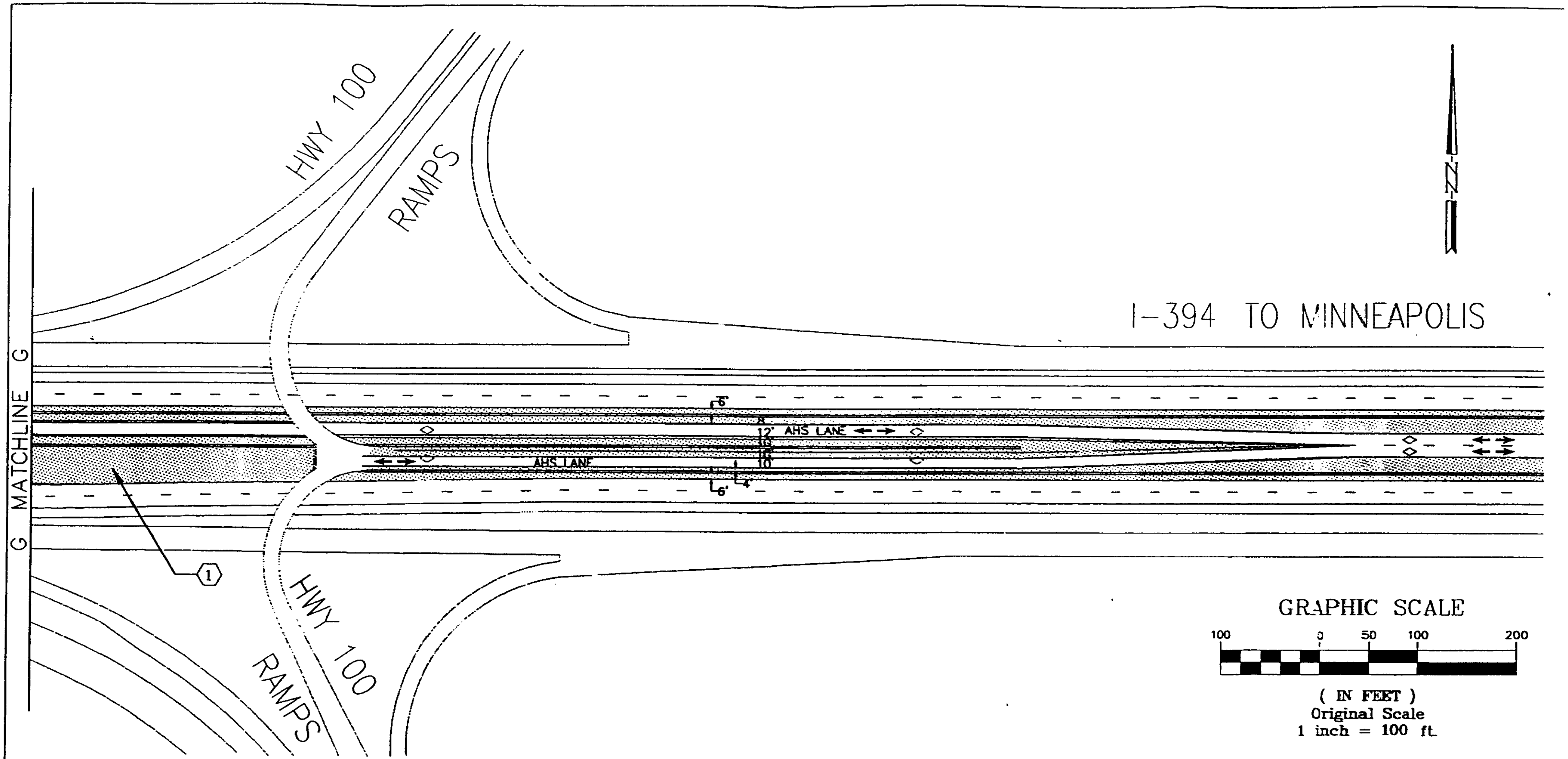
1 inch = 100 ft.
LEGEND
- DENOTES SHOULDER AREA
ISSUES
1 - REMOVE EXISTING BARRIER
DATE: 9/21/94
SHEET 4 OF 8 SHEETS
DESIGNED BY: MTD
CHECKED BY: SAM
DRAWN BY: MTD
FRINGE FREEWAY
SECTION RSC-2C



LEGEND

[shoulder hatch symbol] – DENOTES SHOULDER AREA

ISSUES

(1) – EXCESSIVE AMOUNT OF UNUSED PAVEMENT. MAY NEED TO EXTEND BARRIER TO PREVENT MOTORISTS FROM STRAYING. COULD ALSO RECLAIM MEDIAN FOR LANDSCAPING, CHECK-IN/CHECK-OUT FACILITY, TRANSIT STOP, ETC.

I-394, MINNEAPOLIS TO WAYZATA
FRINGE FREEWAY
SECTION RSC-2C

DATE: 9/21/94 | SHEET 8 OF 8 SHEETS | DWG. REF. MINSHTS
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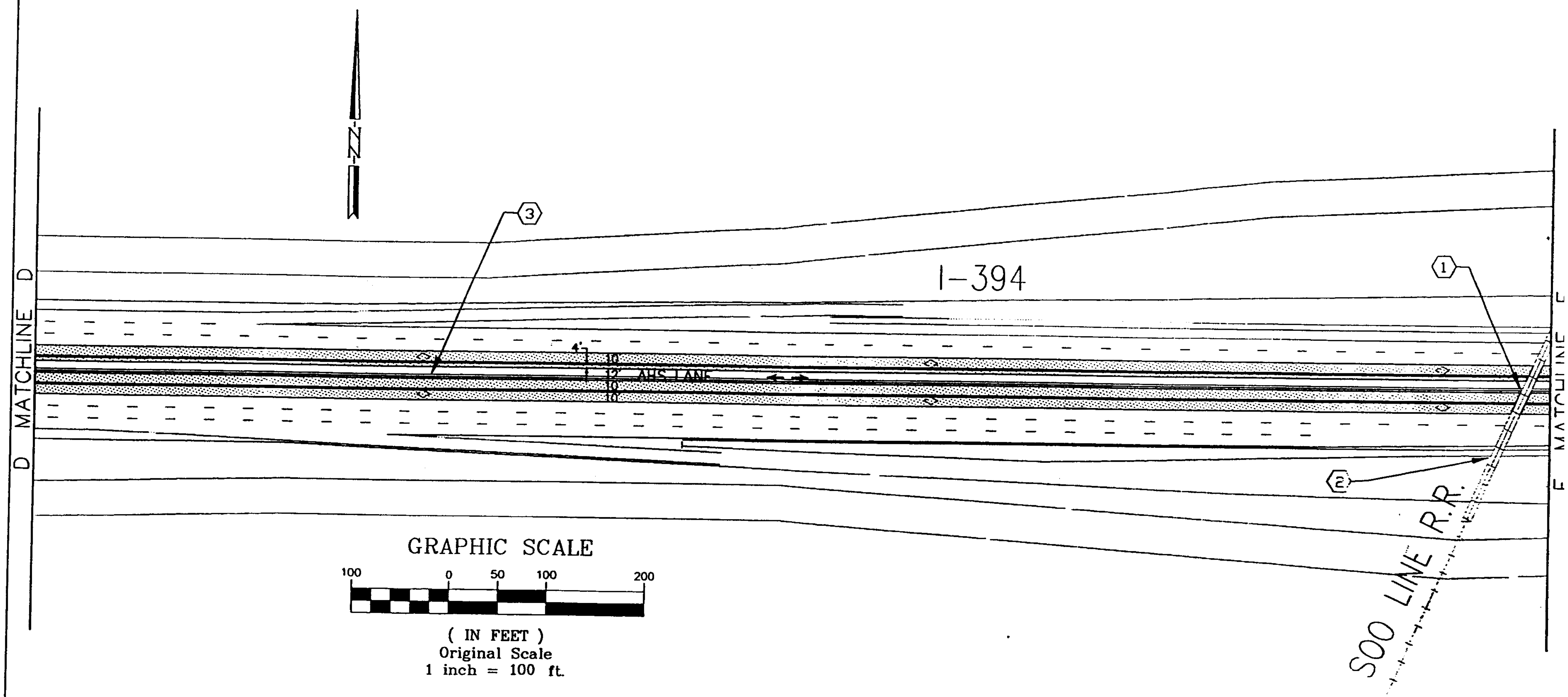

LEGEND

[dotted box] – DENOTES SHOULDER AREA

ISSUES

1. – POTENTIAL CONFLICT WITH CENTER PIER OF OVERPASS STRUCTURE. MAY NEED TO WIDEN AND/OR REALIGN FREEWAY APPROACHING PIER.
2. – WIDENING MAY CONFLICT WITH OVERPASS STRUCTURE ELEMENTS SUCH AS PIERS, ABUTMENTS OR SLOPE PAVING.
3. – REMOVE EXISTING BARRIER

DATE: 9/21/94	SHEET 6 OF 8 SHEETS	DWG. REF. MINSHT6
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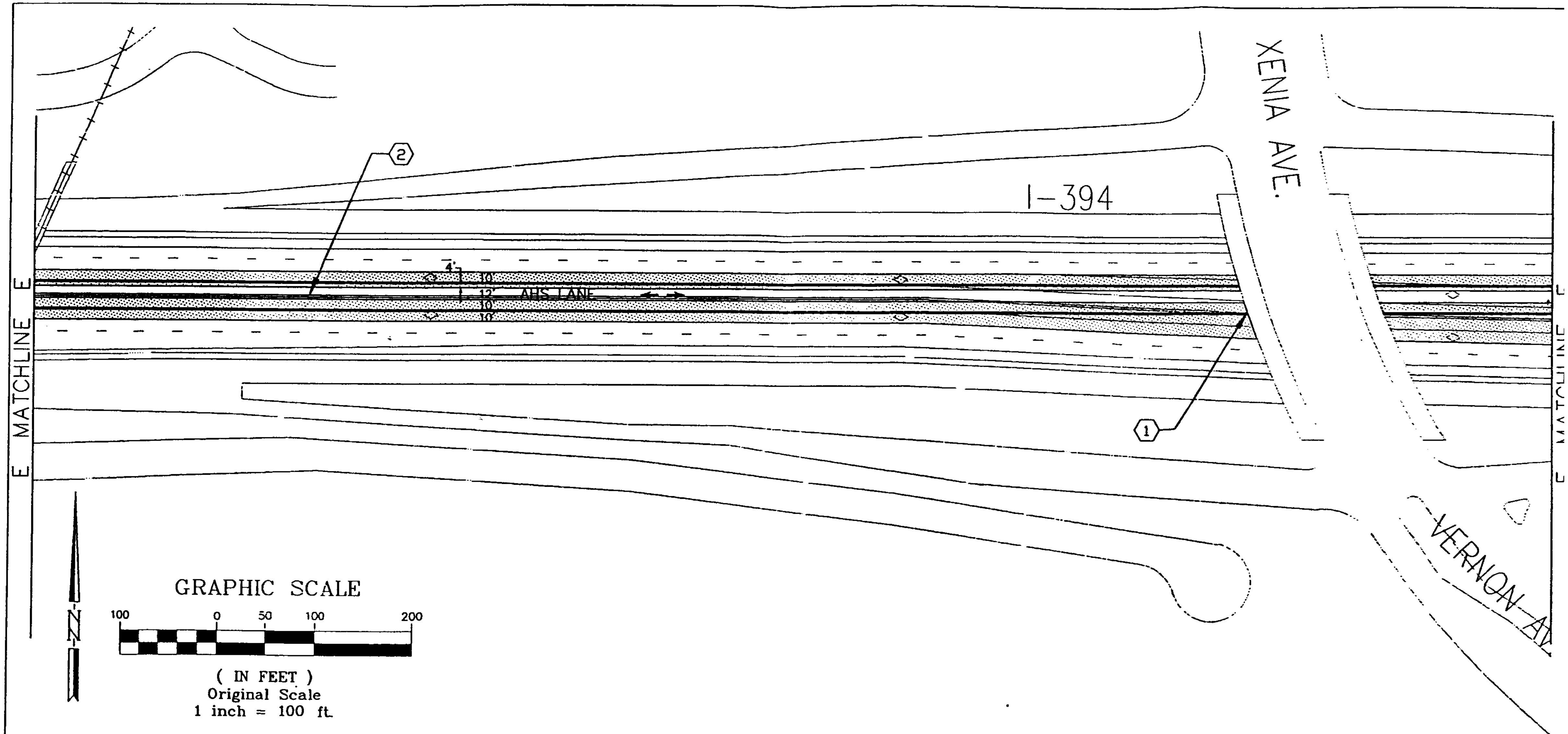
I-394, MINNEAPOLIS TO WAYZATA
FRINGE FREEWAY
SECTION RSC-2C



LEGEND

- DENOTES SHOULDER AREA

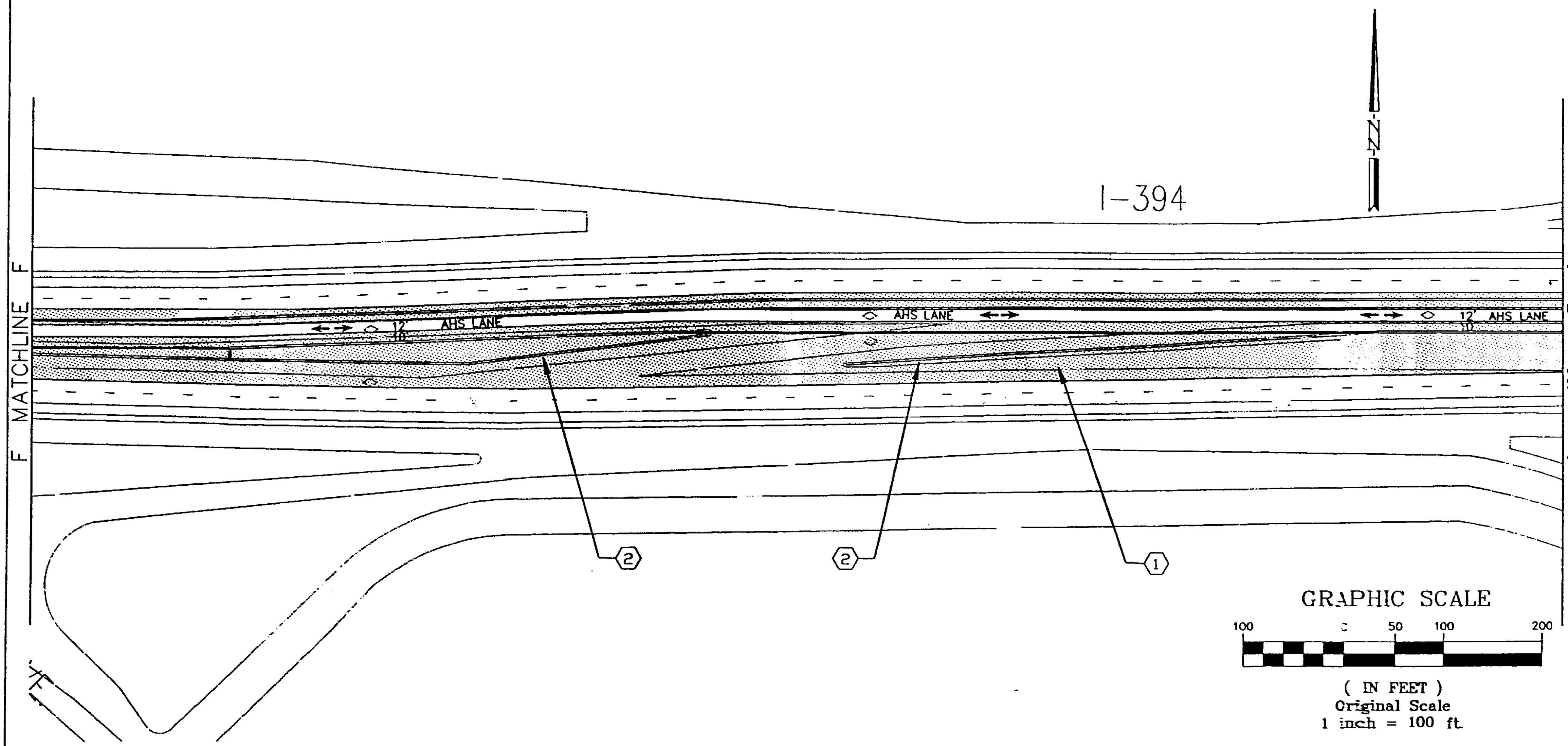
ISSUES

(1) - ALIGN NEW BARRIER WITH CENTER PIER OF OVERPASS STRUCTURE TO AVOID CONFLICT WITH CENTER PIER.

(2) - REMOVE EXISTING BARRIER

DATE: 9/21/94	SHEET 6 OF 8 SHEETS	DWG. REF.: MINSHT6
DESIGNED BY: MTD	CHECKED BY: SAM	DRAWN BY: MTD

I-394, MINNEAPOLIS TO WAYZATA
FRINGE FREEWAY
SECTION RSC-2C



LEGEND

(dotted box) – DENOTES SHOULDER AREA

ISSUES

⟨1⟩ – EXCESSIVE AMOUNT OF UNUSED PAVEMENT. MAY NEED TO EXTEND BARRIER TO PREVENT MOTORISTS FROM STRAYING. COULD ALSO RECLAIM MEDIAN FOR LANDSCAPING, CHECK-IN/CHECK-OUT FACILITY, TRANSIT STOP, ETC.

⟨2⟩ – REMOVE EXISTING BARRIER

I-394, MINNEAPOLIS TO WAYZATA
FRINGE FREEWAY
SECTION RSC-2C

DATE: 9/21/94	SHEET 7 OF 8 SHEETS	DWG. REF. MDNSHT7
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